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AN INTRODUCTION

TO THE

GEOLOGY OF CAPE COLONY

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BY

A. W. ROGERS, D.Sc., F.G.S.

AND

A. L. DU TOIT, B.A., F.G.S.

OF THE GEOLOGICAL SURVEY OF CAPE COLONY

WITH A CHAPTER
ON THE
FOSSIL REPTILES OF THE KARROO FORMATION
BY

PROF. R. BROOM, M.D., B.Sc., C.M.Z.S.

OF VICTORIA COLLEGE, STELLENBOSCH

WITH ILLUSTRATIONS AND COLOURED MAP

SECOND EDITION

LONGMANS, GREEN, AND CO.

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1909

PREFACE TO THIS EDITION.

The first edition of this book was written as one of a series designed by Dr. Muir, Superintendent of Education, to further the study of Natural Science in South Africa. During the five years which have passed since it was prepared considerable advances in our knowledge of Cape Geology have been made, and in this second edition the work has been revised and largely re-written in the light of the new information.

The chief additions are in those parts of the work dealing with the ancient rocks of the north of the Colony, the Karroo system, and the rocks of the volcanic pipes related to the Kimberley group, while there are great advances in the palæontology of the Bokkeveld, Karroo and Cretaceous formations.

In order to keep the size of the book within moderate limits the less important parts of the first edition have been reduced or omitted.

The map has been re-drawn on a larger scale; with the work done by the officers of the Geological Commission has been incorporated the information collected by A. G. Bain, A. Wyley, R. Pinchin and E. J. Dunn, while the Rev. S. S. Dornan very kindly gave us a sketch map of the geology of Basutoland, the result of many journeys made during his missionary work in that country.

To our former colleague on the Geological Survey, Prof. E. H. L. Schwarz, we owe our thanks for the photographs reproduced on Plates XXIII. and XXIV., and for the view on Plate XIV. we have to thank Mr. E. H. Short of the Cape Railways.

Dr. R. Broom has again very kindly contributed a chapter on the vertebrate fossils from the Karroo formation, as well as help in the names and localities of many fossils.

A. W. ROGERS.

A. L. DU TOIT.

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ABBREVIATIONS USED IN THE FOOTNOTES.

Am. J. S.	*American Journal of Science.* Newhaven.
A. S. A. M.	*Annals of the South African Museum.* Cape Town.
G. C. (i.-xiii.)	*Annual Reports of the Geological Commission*, first to thirteenth, for the years 1896-1908. Published during the following year, except in the case of the Report for 1898, which was published in 1900. Cape Town.
G. M.	*Geological Magazine.* London.
N. J. f. Min., etc.	*Neues Jahrbuch für Mineralogie, Geologie und Palæontologie.*
Q. J. G. S.	*Quarterly Journal of the Geological Society of London.*
Rep. S. A. A. A. S.	*Reports of the South African Association for the Advancement of Science.* Johannesburg.
T. G. S. S. A.	*Transactions of the Geological Society of South Africa.* Johannesburg.
T. S. A. P. S.	*Transactions of the South African Philosophical Society.* Cape Town.

A bibliography of papers, etc., on Cape Geology, published before 1905, by Miss Wilman, will be found in *T. S. A. P. S.*, vol. xv., part 5, 1905.

CHAPTER I.

INTRODUCTION.

The backbone of the Cape Colony is the watershed between the rivers that drain into the Atlantic and those which flow south and east into the Indian Ocean. The watershed lies in a general east-north-east direction from the neighbourhood of Ceres and Tulbagh, where two systems of mountains converge, the Cederbergen and those parallel to them on the west, with a north and south trend, and the Langebergen and parallel ranges on the south, with an east and west trend (see Fig. 3). The watershed is formed by the Klein Roggeveld, Nieuweveld, Winterbergen, Stormbergen and Drakensbergen, and as a whole it is the highest belt of ground in the country, although certain peaks in the southern and western mountains rise to a greater height than many parts of the watershed. From this main waterparting the surface slopes gradually northward to the Orange River, by which the greater part of the area north of the watershed is drained. Towards the west coast the country which feeds the rivers running directly to the Atlantic south of the Orange River is considerably broken; the two escarpments of the Roggeveld and the Bokkeveld Mountain, which eventually become one feature about eighty miles north of Calvinia, bring the level of the surface down from some 5,000 feet to 500 feet above the sea. South of the Bokkeveld Mountain (an important escarpment west of Calvinia which must not be confused with the mountains of the Cold Bokkeveld in Ceres) the Cederberg chain commences, and forms, together with its subsidiary parallel ranges, a broad belt of mountainous country rising to the height of 6,000 feet between the Karroo and the coastal district.

The southern drainage slope is also very different in the west and east. In the west there is a sharp drop immediately south of the watershed, and the Great Karroo lies between it and the Zwartebergen, which rise to a height of over 7,000 feet above the sea, and some 5,000 feet above the Karroo. The Zwartebergen, Langebergen, and the minor ranges parallel to them, run nearly east and west, together forming a wide tract of mountainous country which stretches from Tulbagh to the Indian Ocean east of Grahamstown. This belt is traversed by the rivers flowing from the Karroo, generally in deep, steep-sided valleys, which become gorges in the mountain ranges. There are many longitudinal valleys in this region much more open and less steeply graded than those of the transverse rivers into which their waters flow. The country between the Zwartebergen and Langebergen, occupied by longitudinal valleys, lies somewhat lower on the average than the Great Karroo. South of the Langebergen the surface slopes towards the coast, but it is deeply cut into by rivers, and diversified by mountains such as Aasvogel Berg, Pot Berg, and the mountains of Caledon and Bredasdorp.

In the eastern part of the Colony, beyond the Gualana River where the southern mountainous region is cut through by the coast, the descent from the watershed to the coast is more uniform than in the west; it is unbroken by mountain ranges, but is more of the nature of a succession of terraces than a gradual slope. There is thus no area in the east corresponding to the Great Karroo of the west and midlands.

Before describing the geological structure of the Colony, it will be convenient to give a general account of the various groups of rocks that built it up. The classification of these rocks, which will be used in this book, is on pages 4 and 5.

The Pre-Cape rocks are a heterogeneous collection of sediments and igneous rocks both extrusive and intrusive. The sediments can be divided into two great groups, those older than the intrusions of granite and those which were laid down subsequently to the intrusion. It is unfortunately not known whether there was more than one period during which intrusion of granite took place, but it is possible that the Bechuanaland granite is older than that of Prieska and Upington. The later sedimentary rocks were folded and subjected to prolonged denudation prior to the deposition of the Cape system.

Beyond the statement that all these rocks are older than the Devonian (lower half of the Cape system) nothing can be said as to their age, but they must represent an enormous lapse of time.

The Cape system is a group of sandstones, quartzites and shales some 10,000 feet thick lying unconform-

Recent and Sub-Recent Deposits.	Sand Dunes ; Consolidated Dunes and Limestones ; Surface Limestones and Quartzites ; Gravels of Low and High Levels ; Raised Beaches and Deposits Filling Drowned Valleys. Knysna Beds.		Recent Pleistocene and possibly Tertiary.
Cretaceous system	Need's Camp series		Danian ?
	Pondoland Cretaceous series	Umzamba beds	Senonian
		Embotyi beds	
	Uitenhage series	Sunday River beds and those of Brenton	Neocomian
		Wood beds	Neocomian
		Enon beds	Neocomian
Karroo system	Stormberg series	Drakensberg beds	Jurassic
		Cave sandstone	Jurassic
		Red beds	Rhaetic
		Molteno beds	Rhaetic
	Beaufort series	Upper or Burghersdorp beds	Triassic
		Middle Beaufort beds	Triassic
		Lower Beaufort beds	Permian
	Ecca series		Permian
	Dwyka series	Upper shales	Permian
		Glacial beds	Carboniferous
		Lower shales	Carboniferous
	(Unconformity below glacial beds north of lat. 33°)		
Cape system	Witteberg series		Carboniferous
	Bokkeveld series		Devonian
	Table Mountain series		Devonian

	South and West.	Gordonia.	Prieska, Kenhardt and Griqualand West.	Bechuanaland.	Transvaal.
Pre-Cape rocks.	...	Matsap	= Matsap	= Matsap {Upper, Middle, Lower}	= Waterberg system
	Nieuwerust series	Zwart Modder series (relations unknown, older than Dwyka)	Transvaal system	Griqua Town series {Upper, Middle or Ongeluk, Lower} Campbell Rand series Black Reef series	= Pretoria series = Dolomite series = Black Reef series
	Ibiquas, French Hoek and Cango beds	Koras series ?	= ? Ventersdorp system	{Pniel series Kuip series Zoetlief series}	= Ventersdorp system
	...	Not recognised in Cape Colony.		...	Witwatersrand system
	... Intrusion of granite	Intrusion of granite Wilgenhout Drift series?	Intrusion of granite	...	Swaziland system with intrusive granite
	Malmesbury series	Kheis series	= Kheis series {Kaaien beds, Marydale beds}	Kraaipan series ?	
	...	...	...	Intrusion of granite ?	

The foreign equivalents of these rock systems are unknown; probably a large part of them are Pre-Cambrian. The wavy line indicates an unconformity.

ably upon various older formations in the south of the Colony. Marine fossils of Devonian age occur in about 1,100 feet of rock in the middle of the system. Unfortunately these beds have not been recognised in the north, though one of the northern formations, the Matsap series, has been supposed, on quite inadequate grounds, to represent the lower part of the Cape system.

The Cape system is overlain conformably by the Karroo formation along the southern edge of the Karroo, but northwards it is overlapped unconformably by that formation and finally disappears at the north end of the Bokkeveld Mountain in Calvinia, where the Karroo beds lie directly upon Pre-Cape rocks.

The Karroo system, including the Dwyka series, mainly of glacial origin at its base, and the volcanic group of the north-east at its summit, is over 19,000 feet thick, and it covers a greater area in the Colony than any other formation. Consisting chiefly of sandstones and shales without marine fossils this group of rocks is a striking example of that class of formations called continental, and it is of extreme interest on account of the numerous reptiles, ranging in age from Permian to Jurassic, preserved in it. Though of continental origin, an expression which merely implies that the rocks were not formed under the sea, this system does not resemble such rocks as the Bunter and Keuper series of the British Trias; the characteristic red marls and sandstones of the latter are unlike any beds in the Karroo formation, in which red and purple shales play a subordinate part.

The Cretaceous beds have only been found near the coast. They range from Neocomian to Danian in age, though the succession is very incomplete so far as it is known. These rocks include the only fossiliferous marine mesozoic beds yet found in South Africa, shelly limestones, conglomerates and argillaceous shales, evidently formed near a shore. There are other rocks in this system, conglomerates, sandstones, and clays, which contain no fossils or only those of land or fresh-water organisms, and these are the more widespread of the two classes.

The recent and sub-recent deposits probably date back to Tertiary times, though some of them are in process of formation to-day. They cover wide areas in the south, west, and north of the Colony, but the eastern districts are comparatively free of them. There is no need to give further details about them at this stage.

The geological structure of the Cape Colony divides it into two parts,[1] a northern region in which the strata have not been disturbed by earth-movements on a great scale since Palæozoic times, and a much smaller southern region which has been the scene of mountain building and faulting during the Mesozoic period. The transition zone between these two regions is curved; starting from the south-west near the Cape Peninsula

[1] The triple division of the Colony into Pre-Cape Region, Folded Belt and Karroo Region adopted in the first edition of this book is now abandoned, because it has become unsuitable owing to the fact that the Karroo rocks cover a much wider area north of the Orange River than was then suspected. The Pre-Cape Region of the threefold division becomes larger merely by the removal of the covering Karroo rocks by denudation. The present twofold division has the advantage of being based on one structural feature of importance.

it runs northwards round the north end of the Cederberg folds and turns south through the Tanqua Karroo; in the country beyond Karroo Poort it takes an easterly course to the shores of the Indian Ocean between the Gualana River and East London.

The first of these two regions is essentially a country of plateaux, and though it also forms the low-lying coast belt in the west of the Colony it can be conveniently called the Plateau Region; the second or Folded Belt is characterised by folds which have played a very important part in determining its existing surface features.

The plateau region is itself sharply divided into two parts by the presence or absence of the Karroo formation above the very ancient rocks which predominate at the surface in its north-western and northern parts. As yet very little is known of the north-western corner of this region; the accounts given by Wyley and Dunn show that it is largely made of granite and gneiss intrusive in schistose rocks of various kinds, and that there are considerable areas of horizontal quartzites lying on the schists and gneiss. Various opinions have been expressed as to the relationship of these quartzites, but until some one familiar with the several unfossiliferous quartzitic formations in other parts of the Colony has examined them, their significance must remain uncertain.[1] The southern end of the north-western granite

[1] From descriptions in a note-book of the late Dr. Atherstone, Prof. Schwarz infers that the quartzites belong to the same group as the Nieuwerust beds of Van Rhyn's Dorp (*G. M.*, 1908, p. 425).

is found in Van Rhyn's Dorp, where it penetrates the Malmesbury beds. Near Upington the north-eastern part of what is presumed to be the same mass of granite is in intrusive contact with the Kheis beds. Granite again plays an important part in the Vryburg and Mafeking Divisions, but it is not impossible that this granite will prove to be older than the other. The granite of the south-western districts is intrusive in the Malmesbury beds and forms elongated areas parallel to the strike of the latter. There are a few outliers of the Table Mountain series in this narrow southern end of the plateau region; the mountains of the Peninsula and Riebeek Kasteel are examples. Owing to the beds lying nearly flat they are in strong contrast to the ranges made of the same rock to the east of them. North of the Berg River a broad and but slightly flexed layer of the same series covers the Pre-Cape rocks for some fifty miles.

The Pre-Cape sedimentary rocks of the south-western coast belt give rise to but few conspicuous hills, and of these the highest, such as Groenberg near Wellington and the Lion's Rump near Cape Town, owe their existence to former outliers of the Table Mountain series, now removed by denudation. The chief hills, besides the outliers mentioned above, are due to the granite of Paarl, Malmesbury, and the Saldanha Bay country. Further north the Kamies Berg in Namaqualand is a very conspicuous mass of granite.

In the north of the Colony the Pre-Cape sedimentary rocks, unlike those of the south, form long and important ranges, while the granite country is flat and usually covered with a thick layer of sand. The trend of these northern ranges coincides with the strike of the rocks. The longest range is one made by the Lower Griqua Town beds; commencing in the Prieska Division as the Doornbergen with a north-westerly trend they send a branch northwards at Prieska which becomes the Asbestos Mountains in Hay with a north-north-east course for 125 miles; near Daniel's Kuil they bend round and take a northerly course for some twenty miles, then they trend north-north-west for more than sixty miles; beyond the valley of the Kuruman River the range is not a continuous feature, but low hills rising out of the sand at intervals represent it, and they have a northerly trend to beyond Heuning Vlei; near Skelek they bend round to north-east and east-north-east. This long range is formed by the escarpment of the Griqua Town beds facing the limestone plateau of the Kaap, which lies to the east of it. Its sinuous course is typical of all the structural lines in Cape Colony north of the Karroo and east of the southern Kalahari, though the analogous curves shown by the flatter-lying Black Reef beds to the east are more accentuated, and those shown by the highly folded Matsap beds (Langberg-Korannaberg range) to the west are less so. The dip of the beds and the frequency of folds increase westwards, and just as the line of outcrops of beds traversed by a valley more nearly coincides with the strike the higher the beds dip, so in the north of the Colony the boundaries of the formations become less curved in the area of the more highly inclined strata.

In the Langberg-Korannaberg range the beds are in places overfolded and dip towards the west. West of the Langberg there are parallel ranges of the same rocks (Matsap series) and also of the very much older Kheis beds; these hills project from the Kalahari sand, but the Dwyka formation, lying flat, is met with at several places in wells or on the surface in Gordonia, and it is extremely probable that a very large area of the sand-veld is underlain by a thin layer of the Dwyka. This circumstance bears out the conclusion drawn from the study of Prieska, Griqualand West and Bechuanaland, that all the main surface features of those areas, excepting the valley of the Orange River, were in existence during Dwyka times and have been again exposed by the removal of the Dwyka series and higher members of the Karroo system.

The Karroo formation rests apparently undisturbed on all these ancient rocks of the north, and there is much evidence that the main source of the rock *débris* forming the Southern Dwyka was in the north. The base of the Dwyka, however, falls southwards as the valley of the Orange River is approached, and again rises to higher levels south of the river before it dips down under the great area made of Karroo sediments in the central portion of Cape Colony. Whether this fall towards the Orange River is due to a slight synclinal fold, or whether it indicates the presence of a valley or a series of depressions along the course of what is now the Orange River, is still uncertain, but the known facts seem to favour the former conclusion.

The outlines of the northern ranges made of the Pre-Cape rocks are usually soft and rounded, probably because the agency which moulded their surfaces was the southward moving ice of Dwyka times, but, as will be pointed out in a later chapter, the remarkably even sky-lines of many of the ridges made of folded rocks and the flat plateau of the Kaap, cut alike through hard and soft rocks, are probably due to a much later stage of denudation.

South of Prieska and Kenhardt lie the wide plains cut in the Karroo beds, broken only by table-shaped or conical hills due to the occurrence of the hard sandstones of the Beaufort series or to the presence of sheets of dolerite intercalated with the softer sedimentary rocks and by rough country formed by sheets and dykes of dolerite.

The Karroo beds in the greater part of the plateau-region have a synclinal arrangement; to the north of the main watershed they dip south or south-east, to the south of it in the opposite directions; the inclination is very slight, but as it is continued for many miles the effect is to bring in a great thickness of beds, though the surface of the country only rises 2,000 or 3,000 feet except towards the Basutoland border, where there is an additional thickness of some 7,000 feet of the Stormberg series.

The Karroo area is often likened to a basin, but the structure of the southern edge of the basin is very different from that of the northern, as its position is due to folding which took place after the deposition of a considerable part of the Karroo system, while the northern edge marks the stage reached in the denudation of the latter from a gently sloping floor. That the Karroo formation once extended across the southern mountains is proved by its outliers amongst the mountains and the large outlier on the downthrow side of the Worcester fault (Fig. 1), along which the various rock formations up to and including the Ecca at least have been let down against the Malmesbury beds. The southern limit of the Karroo beds is unknown; they may have stretched beyond the present coast.

A very important feature in the plateau region is the abundance of dolerite intrusions. These intrusions avoid the folded belt, but both on the inland side and in the narrow strip still open to observation on

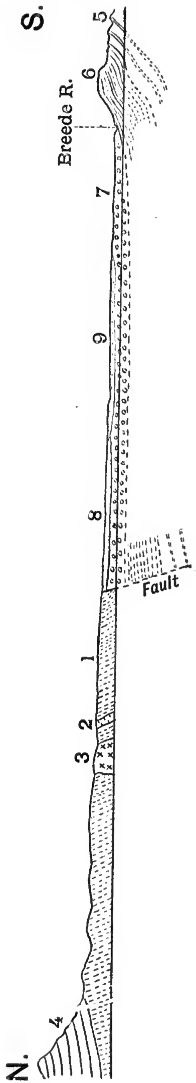


Fig. 1.—Section through the Worcester Fault. Distance 12 miles. Vertical scale $\frac{1}{10}$ in. to 1,000 feet.

1. Slates, etc. } Malmesbury series.
2. Limestone }
3. Granite.
4. Table Mountain series.
5. Bokkeveld series.
6. Witteberg series.
7. Dwyka series.
8. Ecca series.
9. Uitenhage series (Enon beds).

the ocean side of the belt they are found. The intrusions are either nearly horizontal sheets, or steeply inclined dykes. The sheets are confined to the inland side of the folded belt, and also, almost entirely, to the Karroo beds. Individual sheets may extend over or through thousands of square miles. The dolerite outcrops cease abruptly along a line drawn from the Tanqua Karroo eastwards through Beaufort West, and the abrupt escarpment of the Roggeveld and Nieuweveld, along which the surface of the country drops some 3,000 feet to the Great Karroo and the Gouph, is evidently due to the protection afforded by thick sheets of dolerite to the weaker sedimentary rocks and, to a less extent, to the hardening of the latter along the contacts.

Travelling southwards through the Great Karroo one passes almost insensibly from very gently inclined strata to the steeply dipping beds in front of the southern mountain ranges. Though the transition is generally gradual there are places where there is a rapid increase in dip, but these localities are south of the belt of country where the inclination becomes conspicuous.

The folded belt runs in a southerly direction from the neighbourhood of Van Rhyn's Dorp to Cape Hangklip, but from Ceres southwards it also turns eastwards and is continued till it is cut off by the coast near the mouth of the Gualana River.

This area is chiefly composed of the three members of the Cape system, the lowest of which, the Table Mountain series, forms the mountain ranges of the Cederbergen, Drakensteins, Langebergen and Zwartebergen, to mention only some of the more important ones, which are such striking features in the south of the Colony. In addition to the Cape formation, the lower parts of the Karroo system, the Dwyka and Ecca series are involved in the folding, and this fact has great significance in that it proves that the folding took place chiefly after the deposition of the Ecca series. The later limit of the period during which the folds were produced is fixed by the presence of considerable areas of comparatively undisturbed beds belonging to the Uitenhage series lying upon the upturned edges of the folded rocks belonging to all ages from Pre-Cape to Ecca.

The Cape Peninsula and the district north of it, where the Table Mountain series lies nearly flat, are on the outer side of the curved folded belt, and on the inner side, towards which the folded strata have moved, lies the Great Karroo. In the extreme south of the Colony there is an area of slightly disturbed sandstone of the Table Mountain series between Danger Point and Northumberland Point. It is very probable that the folds which form the southern mountains are restricted to a curved belt now cut through by the coast, and that on the ocean side of it there is a large region unaffected by the folds; but by far the greater part of this region is hidden by the sea, and the only remnants open to observation are the west coast belt south of Olifant's River and the strip near Cape Agulhas.

At its broadest part the folded belt is about 100 miles wide, from the south-western corner of the Karroo to Cape Agulhas, and its length along the bend is some 600 miles. The most marked character of the region is the presence of many mountain ranges, which are mostly formed by great anticlinal or arch-like ridges of the folded strata. A glance at the map will show that the general trend of these mountains is roughly parallel to the coast; on the western side the Cederbergen, Witzenbergen, Cold Bokkeveld Mountains, and other minor ranges, run a little west of north; while on the south, where the Langebergen, Zwartebergen, and other ranges of less importance lie nearly east and west, the coast line makes a corresponding change in direction, but the coast cuts diagonally across the folded belt. In the districts between Ceres and Bredasdorp there is an intermingling of the east and north trending folds, forming an area where the forces that produced these folds have given rise to a clearly marked diagonal set with a north-easterly course; the chief ranges due to these north-easterly folds are the great mass extending somewhat irregularly from Cape Hangklip to the mountains south of Worcester, the Hex River Mountains, and the south-west continuation of the Babylon's Tower range south of Caledon. The mountain ranges with a north-east trend are traversed by a weaker system of north-west folds, and are thereby broken up to a certain extent, especially by the synclines or trough-like folds of Houwhoek and Villiersdorp. The intricate effects of the contest between the two sets of forces, that which produced the Cederberg (north and south) system of folds, and that which produced the Zwartberg (east and west) system, so far as the Caledon and Bredasdorp districts are concerned, have been described in some detail in a survey publication.[1]

[1] *G. C.*, iii., p. 42, etc.

There is some evidence in favour of the view that the Cederberg system of folds began to be formed rather earlier than the Zwartberg, but probably each reached its greatest development at about the same period, at some time between the deposition of the Ecca and that of the Uitenhage series.

The folding is most intense in the east and west trending portion of the rocks involved. Northwards from the country between Tulbagh and Karroo Poort the anticlines or arches, into which the rocks have been bent, are less sharp and less numerous than to the east of the same neighbourhood. The anticlines of the Cederberg system gradually flatten out northwards, so that on the latitude of Van Rhyn's Dorp village hardly a trace of the folds is to be met with in the rocks which are so greatly disturbed farther south (see Fig. 2). At the same time the rocks belonging to the Cape formation gradually thin out in such a way that the base of the Karroo formation, the Dwyka series, is found to lie upon lower and

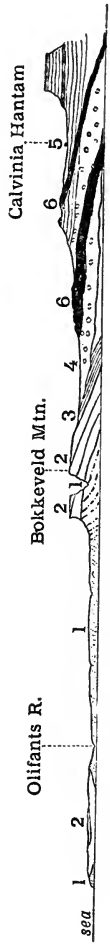


Fig. 2.—Section through the Bokkeveld Mountain escarpment to Calvinia. Distance 72 miles. Vertical scale $\frac{1}{8}$ in. to 2,000 feet.

1. Pre-Cape rocks { Ibiquas series. Malmesbury series.
2. Table Mountain series.
3. Bokkeveld series.
4. Dwyka series.
5. Ecca series.
6. Intrusive dolerite.

lower members of the Cape system, and finally upon rocks of Pre-Cape age, as it is traced northwards from Karroo Poort. We shall see later that this great transgression, or unconformable overlap, is of fundamental importance in enabling us to form an idea of the geological history of the Colony, but at present it will be sufficient to say that at least the chief cause of the thinning out of the Cape system is the denudation which took place before and during the deposition of the Dwyka series.

It has been stated that the folded belt disappears under the sea near the Gualana River, and it would be interesting to find out what becomes of it farther east. It is, of course, impossible to discover the exact state of affairs, but a comparison of the structure of the seaboard of Pondoland with that of the Van Rhyn's Dorp end of the folded belt will give us a clue to it.

In Pondoland some of the rocks which form the folded belt in the south of the Colony reappear on the coast near the St. John's River, but are very different in certain respects from their condition west of the Gualana River. They are found to be very slightly folded; the great anticlines of the south and west have no counterpart there, and the greater part of the Cape formation is altogether absent. The rocks emerge from the ocean with a northerly trend, instead of the east and west strike which they have in the south. At St. John's there is a great block of Table Mountain sandstone, surrounded on all sides by beds belonging to the Karroo formation faulted down against it, but further north-east towards Natal the Dwyka rest unconformably upon the Table Mountain series (see Fig. 3); the accounts of the geology of Natal show that the same condition obtains there, and also that the Table Mountain sandstone (Palæozoic sandstone of Anderson) becomes thinner as it is followed northwards, and finally disappears, so that the Dwyka series rests directly upon rocks of Pre-Cape age. The relation of the Dwyka conglomerate to the Table Mountain sandstone in Pondoland is thus just like that of the same two series in the Bokkeveld Mountain north-east of Van Rhyn's Dorp.

If we imagine the country between Karroo Poort and the latitude of Van Rhyn's Dorp to be removed from observation, we have a nearly similar condition of things on each side of the folded belt, extending from Karroo Poort to the Gualana River, but the relatively raised block of the Gates of St. John's has no analogue in the west. The gradual flattening out of the folds northwards of Karroo Poort has no obvious counterpart in the east of the Colony, simply because the area in which a similar change takes place is under the sea. There is no

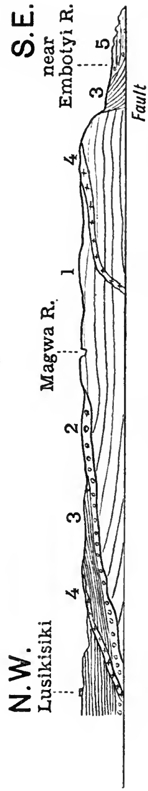


Fig. 3.—Section from the Pondoland coast to Lusikisiki. Distance 11 miles. Vertical scale $\frac{1}{10}$ in. to 1,000 feet.

1. Table Mountain sandstone.
2. Dwyka conglomerate.
3. Umsikaba beds (Ecca).
4. Intrusive dolerite.
5. Cretaceous beds of the Embotyi River.

reasonable doubt that on the sea floor between the Gualana River and St. John's, first the Witteberg and then the Bokkeveld beds disappear, owing to Pre-Dwyka denudation, and that the Dwyka series rests upon lower and lower members of the Cape system, so that in Pondoland it lies directly upon the Table Mountain series, just as it does north of the latitude of Van Rhyn's Dorp. It is very probable that, as in the west, the folds become less marked and practically die out altogether in the same area that shows the thinning out of the Cape system, so in the east the two changes go on together. The comparison of the structure of the northward termination of the folded belt in the west and east of South Africa shows that this end of the continent is built upon a more symmetrical plan than might have been suspected from a mere inspection of the geological map.

The folded belt includes the more thickly populated districts of the Colony outside the Native Territories. Nearly all the various kinds of farming practised in South Africa can be found within this region. The most fertile and valuable land is that situated along the larger rivers flowing through from the Karroo; it is enriched by the silt brought down by them. The poorest soil is found on the sandstone mountains and near the coast, where the natural vegetation is of the kind known as "sour veld". In a region so diversified in climate and rocks as the folded belt, there are naturally many varieties of soil, and we shall have an opportunity of noticing some of these in later chapters.

CHAPTER II.

THE PRE-CAPE ROCKS OF THE SOUTH AND WEST OF THE COLONY.

THE various groups of rocks included under this heading have one character in common, they are older than the Cape formation. In the case of four of the groups, Ibiquas, Cango and Malmesbury, their Pre-Cape age is obvious from the fact that they are found directly beneath the Table Mountain series; but in the case of the other groups, which are found in a region where the Cape formation was either not deposited or has since been removed by denudation, their age has to be arrived at by reasonings based upon the structural features of the country, for no help in correlating these formations is given by fossils.

1. THE MALMESBURY SERIES.

In the south-western districts of Cape Colony the oldest rocks are those to which the name Malmesbury beds was given by E. J. Dunn. Consisting chiefly of slates and quartzites, they were intensely disturbed, invaded by granite and other igneous rocks, and exposed to prolonged denudation before the deposition of the Table Mountain sandstone.

In the immediate neighbourhood of Cape Town the

Table Mountain sandstone, which forms all the higher parts of the Peninsula, lies nearly horizontally, and below it are seen slaty rocks dipping at very high angles, with a general north-north-westerly strike, accompanied by a large intrusion of granite. The slaty rocks are found to extend northwards at least as far as the northern boundary of Van Rhyn's Dorp where the huge area occupied by the Namaqualand granite is entered upon. This large area of Malmesbury beds occupies the greater part of the divisions of Malmesbury, Piquetberg, Paarl, Stellenbosch, and Somerset West. A strip of similar rocks forms the low ground in the Tulbagh valley. Near the town of Worcester the strip becomes narrower and extends south-eastwards as far as Swellendam, a distance of seventy miles, as a band averaging about two miles in width overlain to the north-east by the Table Mountain sandstone of the Langebergen, but cut off on the south-west by the great Worcester fault which has a downthrow of over 12,000 feet near the town of Worcester (Fig. 1). Inliers of similar rocks have been found at Eland's Kloof (near Villiersdorp), in the Zondag's Kloof east of Stanford (Caledon Division), and between Elim and Bredasdorp; each of these inliers is surrounded by the sandstones of the Table Mountain series. Rocks that can best be placed with the Malmesbury beds are found in Mossel Bay, George, and near Port Elizabeth.

The most abundant rock in the series is a blue arenaceous clay-slate, or very fine-grained argillaceous quartzite with imperfectly developed cleavage. Small flakes of white or yellowish mica are often sufficiently abundant to give a lustrous appearance to the cleavage planes. The country occupied by these beds is rather flat and has a regular rainfall; the slates are usually decomposed to a depth of many feet, giving rise to a clayey or sandy material of white, yellow, brown or red colour, and are hidden over wide areas by a thin clayey soil or covered by other superficial deposits, often of considerable thickness.

Outcrops are not abundant, and as the beds are nearly always found dipping at high angles and are obviously repeatedly folded, the true structure of the area has not yet been ascertained; only in Van Rhyn's Dorp has any definite order of succession been made out.

The slaty rocks sometimes become very micaceous, and such sericitic phyllites are well developed in the Tulbagh valley, and to the south and east of Piquetberg. They may pass into impure quartzites, as for instance in the hills north-east of Moorreesburg and the Tigerberg group, but pure quartzites are not often met with. Gritty rocks are common and by the presence of felspar pass into felspathic grits, usually very much cleaved, as for example on the Verloren River in Piquetberg and in Van Rhyn's Dorp. Schistose felspathic rocks, which are perhaps sheared arkoses, occur immediately north of the town of Worcester. In Van Rhyn's Dorp[1] there is greater lithological variation in the series, and it can be divided into a basal group, black slates and phyllites; a middle one, crystalline limestones with interbedded black slates and limonite beds; and an upper one, slates

[1] *G. C.*, ix., p. 13.

and phyllites with thick bands of schistose quartzite. The whole series has been folded, usually isoclinally, that is the dips of both limbs of the fold are inclined in the same direction, to the west. The middle or Aties group is the most interesting and occupies a belt of country at least sixteen miles wide across the strike from Van Rhyn's Dorp westwards. The limestones which are so abundant in this division are usually blue or grey in colour, but dark varieties are also found; carbonate of magnesium is contained in some of them. Along with the folded limestones are black highly carbonaceous and pyritic slates, and also layers of brown or black limonite. In the Kobe Valley there are dark red banded jaspers in contact with the limestone.

Thick bands of crystalline limestone are found interbedded with the slates near Piquetberg, Saron, Vogel Vlei (south of Porterville Road Station) and on the Berg River near Hermon. They also occur at Bakoven's Hoogte between Ashton and Swellendam, in Dassie's Hoek near Robertson in association with black slates, and in thin bands north of Worcester. Schists containing the chloritoid mineral ottrelite are found in thin bands near the junction of the Malmesbury beds with the unconformably overlying Table Mountain series in Waai Kloof near Worcester (Plate I.) and north of the town of Swellendam. In both cases thick quartz schists occur on one side of the ottrelite schist, but no granite or other intrusive rock has been found penetrating the intensely compressed slates in the immediate neighbourhood. In George there is an elongated area of slates and quartzites, the former being sometimes

Plate I.—Waai Kloof, Worcester. The Table Mountain sandstone is folded and lies unconformably upon the quartzites and ottrelite-schists of the Malmesbury beds.

black, penetrated by masses of granite and numerous granitic veins.

Crystalline limestone, slates and quartzites occur at the Maitland Mine a little to the west of Port Elizabeth.

Veins of quartz are abundant in the Malmesbury beds. In Van Rhyn's Dorp they have sometimes been broken up by earth-movements and the fragments rounded so as to simulate the pebbles in a conglomerate. At places the veins have been prospected for gold but without gratifying results.

The general strike of the rocks classed in this series is to the west of north in the western part of the Colony, approximately parallel to the trend of the Cederbergen and the other ranges in the west, which were formed chiefly after the deposition of the Ecca series; but in the south, between Worcester and Swellendam, in Bredasdorp, Mossel Bay, and George, the strike of the Malmesbury beds is on the whole nearly east and west, roughly parallel to the great southern mountain ranges. This change of strike in the Malmesbury beds may perhaps to a very small extent be due to the forces which produced the folds in the overlying rocks; but as the dip of the lower beds is generally far higher than the dips observed in the unconformably overlying rocks, it is impossible to thus account fully for the change in the direction of strike of the Malmesbury beds as they are followed eastwards. It is certain that these rocks were folded almost as much as we now see them before the deposition of the Cape formation, and the general parallelism between the two systems of folds, older and younger than the Cape formation, points to the repetition of the folding along the same lines at a great interval of time.

2. The Granite Intrusions.

The Malmesbury beds have been invaded by masses of acid igneous rocks, granite and gneiss principally, and have been metamorphosed by them. The intrusions are elongated in outline and lie with their longer axes parallel to the strike of the invaded sediments: they form the highest ground in the Pre-Cape area with the exception of the outliers of Table Mountain sandstone.

The largest granite area is that which stretches from St. Helena Bay south-south-east to Klein Dassen Berg, a distance of seventy miles, and the highest points reached by the granite are Kapoc Berg and Contre Berg, both over 1,500 feet above the sea; on the lower ground the rock is usually concealed by blown sand, limestone or lateritic ironstone.

Saldanha Bay is a deep inlet in this mass of granite. On the western edge of the granite, along the shore near Paternoster, Danger, and Saldanha Bays, large inclusions of slate are frequently seen in the igneous rock, indicating the proximity of the Malmesbury beds; the edge of the intrusion is probably not far to the west of the present coast line.

Many varieties of granitic rock are found in this great area. The most abundant perhaps is a two mica (*i.e.*, with both black and white mica) granite with orthoclase as the chief felspar. Tourmaline is often present in the rock near Darling. Every gradation between a normal granite and a gneiss, in which the foliation structure can be seen in even a small fragment, can be found; the massive granite is seen in the interior of the area and the foliated rock near the periphery, but this rule is not without many exceptions. There is no general difference in mineralogical composition between the granite and gneiss; the structural characters which separate the gneiss from the granite seem to have been given to the rock during its consolidation, for the gneiss does not show evidence of a great amount of crushing or rearrangement of its component minerals after it solidified. The foliation planes lie in the same direction as the strike and cleavage of the sedimentary rocks in the neighbourhood; a similar direction is at places observed in the arrangement of the large porphyritic crystals of orthoclase that are occasionally found in great numbers in the massive granite, which shows no other parallel structure. There is no evidence of a difference in age between the granite and gneiss, and the gradual coming in of the gneissose structure as the area is traversed in various directions points to the whole mass being the product of one period of igneous activity.

Large and small veins or dyke-like bodies of micro-granite and quartz-porphyry with a micro-granitic base are found towards the edge of the area in many places. Near Hoetjes Bay the quartz-porphyries are especially abundant. Near Darling a mass of quartz-porphyry has a well-developed parallel structure, and may be considered to bear the same relation to the massive quartz-porphyry as the gneiss does to the granite.

In the hills to the south and west of Darling there are some remarkable rocks enclosed by the granitic gneiss; they are sharply defined angular or rounded lumps of various kinds of granulite. The constituent minerals are, quartz, plagioclase felspar, sphene, and magnetite, together with one or more of the following, biotite, colourless angite, garnet, and pale brown hornblende of an unusual type. These rocks often have a parallel structure, which, however, does not conform to the foliation in the gneiss. These inclusions have some resemblance to certain of the granulites in the Marydale beds of the north, and are to be regarded as metamorphosed sedimentary or igneous rocks enclosed by the intrusive granite. At present similar rocks outside the granite are not known in the south of the Colony.

A few miles east of the southern end of the great mass of granitic rock just described is the irregularly shaped area of granite on which the town of Malmesbury is built. At the south end of this mass is the rugged mountain called Paarde Berg. The granite area is about twenty miles long and six wide, and lies in the direction of strike of the Malmesbury beds. The rock is much less varied in this area than in the larger mass to the west, and is mainly a rather coarse biotite-granite with porphyritic orthoclase, but fine-grained granite composed of the same minerals, and coarse pegmatites are not infrequent. There seems to be no gneiss in this area.

South-east of Paarde Berg is the Paarl Mountain with the well-known group of smooth, naked granite crags on the summit. The most abundant rock in the Paarl Mountain is a biotite-granite. Dykes of quartz-porphyry in continuity with the main mass of granite traverse the surrounding slates along their strike. No gneiss has been observed in this mass.

On the east side of the Berg River between Wellington and Paarl is a long, narrow area of granite overlain by the sandstones (Table Mountain series) of the Klein Drakensteins. This mass extends eastwards down Du Toit's Kloof. Both this granite and the Paarl Mountain rock have a more northerly direction than the other intrusions, and a corresponding change of strike is noticed in the Malmesbury beds of the neighbourhood.

South of the Paarl granite area, in the French Hoek valley, there are several inliers of granite and quartz-porphyry. One variety of the latter is a striking rock having large twinned salmon-pink orthoclase crystals set in a grey-blue fine-grained stony ground mass. The somewhat irregularly shaped mass of Pniel and Stellenbosch is nearly connected to that of French Hoek on the east and to that of Bottelary and Helderberg to the west. Gneiss enters largely into the constitution of these bodies of granitic rock, and, as in the case of the great intrusion on the Saldanha Bay coast, there is no evidence here that the intrusion of the foliated rock was of later or earlier date than the massive granite. In places, such as certain parts of the mountain slopes on the left bank of the Jonker's Hoek stream, the gneiss has been crushed along planes parallel with the direction of the dominant structural lines in the neighbourhood, the cleavage and strike of the slates, and the foliation planes of the gneiss; the crushing occasionally resulted in the production of a rock more like a gritty schist than a gneiss, but this extreme stage is connected with the uncrushed rock through breccias of different degrees of coarseness.

The granites of the Paarl and Stellenbosch districts contain a fair amount of microcline, a variety of felspar which is rare in the Saldanha Bay and Darling area. On the western edge of the Bottelary mass cassiterite or tinstone occurs along with wolframite and tourmaline in quartz veins and also in greisen or quartz-muscovite rock in a gneissose granite.

Near Somerset West there are two masses of granite; the smaller one, Schaapen Berg, just east of the village, contains some interesting varieties of rock. The main mass of the intrusion is a biotite-granite with little muscovite, but the muscovite is very abundant in certain places and the felspar decreases in amount, and may disappear completely, so that the rock becomes a greisen. In other parts tourmaline is extremely abundant, sometimes giving rise to schorl rock, composed of tourmaline and quartz only. At other places andalusite, showing a beautiful pink tint under the microscope, forms a large part of a rock composed of quartz, tourmaline, muscovite, andalusite, and apatite.

The granite underlying a great part of the sandstone of Table Mountain and the other mountains of the Peninsula has been described by many previous writers. Professor E. Cohen[1] of Greifswald has described in detail the granite and the altered clay-slate near it, from the immediate neighbourhood of Cape Town; he was

[1] E. Cohen, "Geognostisch-petrographische Skizzen aus Süd-Afrika," *Neues Jahr. für Min.*, etc., p. 460, 1874.

the first to record pinite, an alteration product of cordierite, in the biotite-granite there.

The contacts of the granite and clay-slate at Sea Point and in the Platte Klip ravine have long attracted considerable attention.

On the beach at Sea Point the junction of the two rocks is an extremely interesting one. First of all some intrusions of very fine-grained granite are found cutting across the tilted and much indurated dark spotted slates. A short distance farther to the south-west the latter are penetrated by such a network of granite veins that an intimate mixture of slate and granite, forming a belt approximately 100 yards wide, lies between the spotted slates and the granite. A remarkable feature is the coarsely porphyritic nature of the granite in contact with the slates and in the narrow veins that penetrate them. In many of the stripes of slate the bedding planes are still recognisable, and their junctions with the granite are sharp; in others there is a gradual transition from the sedimentary to the igneous material, and grey streaky rocks have been produced in which well-formed orthoclase crystals often-form "eyes". It is clear that under the influence of the molten granite fragments of slate were softened or even melted, and became partially incorporated in the invading magma; the whole character of the belt of mixed rock indicates a drawing out of the composite mass while yet plastic. Further west isolated streaks and fragments of slate occur in the porphyritic granite. This zone of mixed rocks can be traced from Sea Point to the foot of Table Mountain.

Small areas of granite intrusive in the Malmesbury beds are known in the south of Caledon, in the Hemel en Aarde and Zondag's Kloof valleys, and again in the western part of Bredasdorp.

In the narrow strip of Malmesbury beds north of the Worcester fault there are at least three granitic intrusions, all of which have been considerably affected by earth-movements since their intrusion, and to some extent probably by movements during their consolidation. There is an abundance of phyllite-gneiss, a rock looking very like a highly micaceous clay-slate with "eyes" and thin strings of obviously igneous material, composed of quartz, orthoclase and mica. The orthoclase crystals often form the "eyes" with little other granite material in the same lenticular area. The largest mass of granite forms the high ridge just west of Robertson.

The last granite area in the south of the Colony that must be mentioned is the intrusion in George.[1] This mass is about thirty miles in length from west to east and from four to eight miles wide; in the east there is a dyke-like offshoot which spreads out into the Touw's River boss. Round the borders of these masses the strata are heavily injected with granite dykes. The granite varies greatly in composition, but is for the most part a muscovite variety though biotite-granite is represented in places; tourmaline and fluorite are also found. As a result of shearing, portions of the granite have acquired a gneissose structure, while basic intrusions have been altered into hornblende schist.

[1] *G. C.*, x., p. 51.

Only the extreme southern end of the Van Rhyn's Dorp-Namaqualand granite mass has as yet been examined in detail.[1] The rock is principally a biotite granite with microcline felspar but it passes into a gneiss; there are many other types represented such as augite and hypersthene-granulites, amphibolite, etc., while in the Langberg region the bulk of the gneiss is garnetiferous. Around Bitter Fontein there are some peculiar schists veined by the granite and faulted on the east against the Ibiquas beds. They include mica-schists, quartz-schists and a peculiar sillimanite-cordierite gneiss.

Contact Metamorphism.

The granite has in nearly every case produced considerable mineralogical changes in the surrounding rocks. The result varies considerably in intensity and nature, depending chiefly upon the character of the rock invaded. Highly quartzitic rocks are the least affected, and the alteration seems to increase with the clay content of the original slate; hence at some distance from the granite, traces of metamorphism can only be recognised in certain of the more susceptible slaty beds.

Around the Paarl, Stellenbosch and Somerset West granites the clay-slates become spotted at a distance of about 300 yards from the contacts; along the Cape Town granite, however, the belt of "spotting" is fully a mile and a quarter wide. The spots become larger and more numerous as the contact is approached, at the same time very minute flakes of red-brown mica are abundantly developed. The spots are found in thin sections

[1] *G. C.*, ix., pp. 19-23.

of the rocks to be clear areas in a finely crystalline quartzose ground mass containing biotite. These clear spots are composed of very minute crystalline grains of a faintly greenish tinted mineral, which is probably cordierite. Small felspars, recognisable by their twinning, have been developed along with muscovite close to the actual contact.

The inclusions of slate in the body of the granite become more and more metamorphosed as the distance from the junction increases, ultimately forming dark coloured patches which are rich in biotite; they sometimes contain cordierite and garnet, and retain no trace of clastic structure. Along the Victoria Road between Sea Point and Clifton a huge inclusion of slate has been all but absorbed by the granite, and has been altered into a banded gneissic rock, which shades off into the enveloping granite.

In several places east of the Darling granite, and in the George district, the slates become highly micaceous near the contact and pass into typical mica-schists, quartzose rocks which glisten owing to the innumerable flakes of pale mica arranged parallel to one another.

At Zwart River Bridge in George there is a magnificent section of andalusite schist,[1] a rock composed of andalusite, mica and quartz; the crystals of andalusite are often over two inches long. The schist occurs within five yards of a remarkably coarse muscovite-biotite granite dyke, which also contains tourmaline.

On Klip Drift Extension in Van Rhyn's Dorp[2] some

[1] Schwarz, *Rec. Albany Museum*, ii., p. 164, 1907.
[2] *G. C.*, ix., p. 17.

magnesian limestone belonging to the Malmesbury series has been altered by the granite to a cream-coloured marble containing crystals of phlogopite mica and minute specks of a black mineral, probably graphite. Some distance farther to the west the granite has penetrated quartzite, and angular blocks of the latter have been wedged off and enveloped by the intrusive rock. The quartzite has become impregnated with granitic material, and felspar has been developed in it along with a little mica.

Basic Intrusions.

At several places in the south-western districts igneous rocks of more basic composition than granite occur as dykes in the Malmesbury beds and in the granite. The dykes in the Peninsula, consisting of augite, plagioclase, and magnetite, may be regarded as belonging to the group of the Karroo dolerites. Near Somerset West there are intrusions commonly showing prisms of plagioclase felspar ophitically enclosed in augite, but the latter has been partially or wholly changed to pale green hornblende (uralite) and in some cases there has been a further alteration into chlorite; the ilmenite has been converted into leucoxene. At Gordons Bay there are small diabase dykes of this type, but more highly sheared and altered.

Some interesting rocks, which may be called diorites and quartz-diorites, form rather limited dyke-like masses in the granites of the Malmesbury district. At Klein Paarde Berg there is a broad dyke about a mile long, composed of hornblende, felspar, mica, quartz, magnetite, apatite and zircon. It is a holocrystalline rock, and the hornblende often encloses the felspar crystals, so as to give the rock a partly ophitic structure; some large crystals of mica (biotite) behave in the same way. Most of the felspar belongs to the oligoclase series of the plagioclases, but there are patches of a very much altered felspar, strongly contrasted to the clear crystals of plagioclase, which are very probably orthoclase. Quartz is present in considerable quantity, filling up the spaces between the other minerals. The rock is little altered as a whole, but some of the mica is replaced by chlorite, and some epidote, derived from the alteration of other constituents, is present. Another variety of diorite in this neighbourhood contains the same minerals as the one just described, but monoclinic pyroxene, with the characteristic diallage structure, is present in considerable quantity, forming in thin sections ophitic plates enclosing felspar. The pyroxene sometimes forms complicated intergrowths with the hornblende and also occurs in the centre of large hornblende crystals; in such cases one set of prism cleavages is common to both minerals.

In the gneiss of Klein Dassen Berg there is a dioritic dyke intruded parallel with the foliation planes of the gneiss. The rock of this dyke is rather different from the Klein Paarde Berg rock, in that the constituent minerals, plagioclase, hornblende and quartz, form nearly equal-sized grains, and none of them have any proper crystal faces; the structure is typically granulitic. At Yzer Fontein Point is a large mass of hornblendic rock, coarsely crystalline, with a banded structure; some thick layers are formed entirely of green hornblende, and others, usually thinner, have a fair proportion of plagioclase in them. These dioritic rocks seem to be confined to the Malmesbury district.

In the George granite there are some dykes of hornblende-schist, composed of long and rather fibrous crystals of green hornblende, arranged parallel to one another, with a smaller quantity of quartz and plagioclase grains between them, and a still smaller amount of epidote. This rock is evidently a highly altered basic dyke, but there is as yet little evidence of its original nature.

3. The Cango Series.

In the Cango district, the country near the northern boundary of Oudtshoorn on the southern flank of the Zwartebergen, there is a group of sedimentary rocks older than the Table Mountain sandstone, and therefore usually classed with the Malmesbury beds. There are, however, so many peculiarities in the Cango rocks which separate them from the bulk of the Pre-Cape rocks of the Malmesbury and other divisions in the south-west of the Colony, that it is advisable to distinguish them by some other name; the term Cango conglomerate[1] has already been used for a prominent band of rock in the series, and it will be convenient to call the whole group the Cango series.

The series forms a lenticular area about seventy miles in length from east to west, from near Amalienstein (Ladismith) to some few miles east of Meiring's Poort, and at the most about nine miles wide. The Table

[1] *G. C.*, iii., pp. 7, 68, etc.

Mountain series bounds the area on the north, and the southern limit is formed by the conglomerates of the Uitenhage series between Meiring's Poort and Calitzdorp, a distance of fifty miles; west of Calitzdorp the sandstones of the Table Mountain series overlie the Cango beds along their southern limit, and farther west again the sandstone is faulted down against them, the fault being so formed that its throw increases and brings the Bokkeveld beds into contact with the Cango; some miles east of Meiring's Poort, also, the Bokkeveld beds are faulted down against the Pre-Cape rocks, and there can be no doubt that this fault, exactly comparable to the Worcester fault, is continued westwards under the covering of Uitenhage beds at least as far as Calitzdorp, and is probably continuous with that already mentioned west of the village (see Figs. 4 and 5).

Along almost the whole length of the northern boundary the Table Mountain series dips at a high angle southwards below the Cango beds, and the latter dip at approximately the same angle in a southerly direction. At the south end of the Gamka Poort, where there is one of the very few clean-cut sections of the junction of the two formations, there appears to be a conformable passage between the two. At other spots, however, such as the south end of Meiring's Poort, the Table Mountain series dips steeply to the north, and lies unconformably upon the older beds which dip at a still higher angle to the south; the contact of different members of the Cango beds with the base of the Table Mountain series at various points corroborates the evidence of the Meiring's Poort section, so there is no

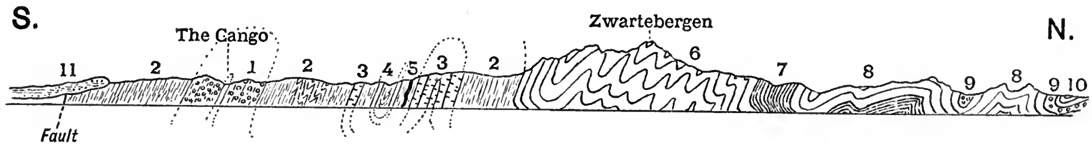


FIG. 4.—Section through the Cango and Zwartebergen 11 miles east of Prince Albert village. Distance 20 miles. Vertical and horizontal scales are the same.

Cango series {
1. Conglomerate.
2. Slates.
3. Limestone.
4. Porphyroid.
}

5. Intrusive dolerite dyke (altered).
6. Table Mountain series.
7. Bokkeveld series.
8. Witteberg series.
9. Dwyka series.
10. Ecca series.
11. Uitenhage series.

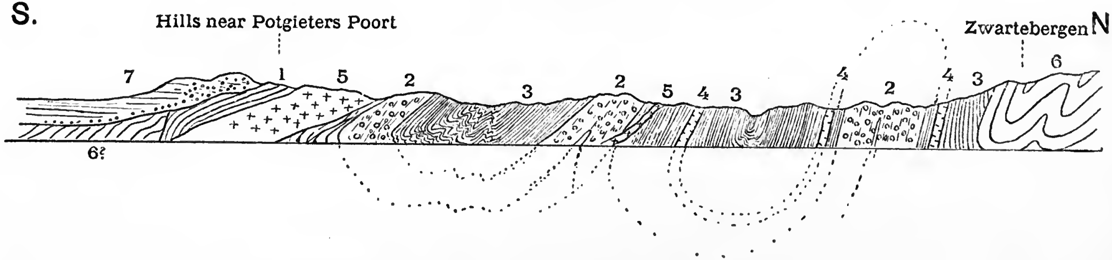


FIG. 5.—Section through the Cango from Potgieter's Poort to the Zwartebergen. Distance 20 miles. Vertical scale $\frac{1}{12}$ in. to 1,000 feet.

Cango series {
1. Quartzites.
2. Conglomerate.
3. Slates.
4. Limestone.
}

5. Intrusive dolerite (altered)
6. Table Mountain series.
7. Uitenhage series.

doubt that the junction is an unconformable one. It is very probable that the Table Mountain sandstone was deposited upon the then nearly horizontal Cango beds, which had suffered some denudation, so that the base of the former group rested upon different horizons of the latter series at different localities. During the great earth-movements that produced the Zwartebergen the two series were together folded and inverted, so that at places the older beds appear to overlie the younger conformably.

The Cango beds usually have high southerly dips, but in the neighbourhood of Kruis River, west of the road up the Zwartberg Pass, the strike is north-east. The top or bottom of a fold is occasionally seen; this indicates that the series is thrown into isoclinal folds, and that the observed great thickness of southerly dipping beds is really due to the repeated folding of a much smaller thickness of rocks. The true succession of the members of the series is rather uncertain, and the base has not been found.

The series consists of conglomerates, quartz-felspar grits, quartzites, slates and limestones, in all a very considerable thickness of rock, not under 10,000 feet. These are accompanied by intrusive rocks of the nature of diabase or altered dolerite (see Fig. 5). The conglomerates lie next to the Table Mountain sandstone in the western part of the area; in the central portion, the limestone lies in a similar position, elsewhere slates or quartzites are in contact with the sandstone. At the Gamka Poort thick bands of conglomerate are in contact with the Table Mountain series. There are several varieties of conglomerate in the Cango beds, differing chiefly in the nature of their contained pebbles and in the amount of shearing they have undergone. In the west, on the hills north of the Ladismith Road near Vaartwell, the conglomerate has been sheared to such an extent that the original forms of the pebbles (slaty rocks and vein-quartz) are no longer recognisable, and in many cases the exact limit between pebble and matrix is indefinite. Farther east the conglomerates are more normal in character, but the effects of shearing are still very evident. In Schoeman's Poort, where excellent sections through the conglomerate are exposed by the roadside, large pebbles or boulders of granite and diabase are seen in it. The occurrence of these is interesting, as it proves the Cango beds to be later in age than some rocks—possibly the Malmesbury beds—which were invaded by granite and diabase before they furnished sediments for the building up of the Cango beds. So far as is known at present there is no unconformity at the base of the conglomerates of which there are at least two bands, and although in the Grobbelaar's Valley, and other places farther west, slates are seen on either side of the steeply inclined conglomerate, it is even difficult to decide which is the top and which the bottom of that rock. It may be that the bottom is nowhere seen, and the slates on either flank of the conglomerate overlie the latter.

A remarkable group of beds, formed chiefly of various-sized fragments of quartz and felspar, extends for a considerable distance along the strike of the Cango series, half a mile north of the conglomerate between

Grobbelaar's River and Matje's River. The felspar occurs in fragments of such size and form that in places the rock has the appearance of a porphyritic granite. When examined under the microscope in thin sections the quartz and felspar are seen to be broken crystals, although the crystalline form of the quartz is occasionally seen. The felspar is mostly microcline, but albite is frequently, and orthoclase occasionally, met with. These minerals are enclosed in a ground mass chiefly composed of small grains of quartz and minute flakes of sericite, a pale micaceous mineral; small flakes of brown mica are sometimes found taking the place of the sericite. The mica forms a thin casing round the large grains of quartz and felspar, and the two latter minerals are often seen almost in contact with a very thin film of sericite between them. The sericite occurs in this rock in the same manner as in many gneisses and conglomerates that have been subjected to great pressures in the earth's crust. In some localities the rock shows a distinct schistosity, and in thin sections the large quartz fragments are seen to be elongated in the plane of schistosity, and have patches of interlocking grains of quartz at their two ends, as if the material had been removed from the sides of the fragments and deposited at the ends. The minute sericite flakes lie in one direction, along the planes of schistosity. The quartz-felspar rock of the Cango appears to have been a sedimentary rock composed chiefly of fragments of quartz and felspar, in which the micaceous minerals have been developed by pressure; it seems therefore to be an indurated arkose. This view is supported by the fact that in places bedding planes are distinctly seen and the rock passes into felspathic grits. Moreover, in the valley from which the Cango caves are entered three beds of conglomerate—a quartz-felspar grit with rounded boulders, pebbles of granite, mica-schist, quartzite, crystalline limestone, and vein-quartz—are seen in the stream bed below the caves.

There are many bands of limestone in the Cango beds, sometimes of great thickness; they are lenticular in form, but to what extent this is due to folding has not been determined. The chief limestone band is that which is in contact with the sandstones of the Zwartebergen near the south end of the Zwartberg Pass. It extends for some fifteen miles eastwards, and in it are the famous Cango Caves.[1] The cave, at least that part known in 1897, is nearly 750 yards long, and is probably of still greater extent. The explored portion of this cave lies in a nearly straight line. There can be no doubt that the cave has been formed by the solution of the limestone, aided by the breaking away of the roof and sides and the removal of the *débris* by running water. The cave has not been sufficiently explored to explain its formation fully, and the level of the floor at various points is not known. The floor itself is at least partly made of *débris* cemented with calcareous tufa and stalagmite. The walls and roof of the cave, in those parts which have not been disfigured by the smoke of candles, are very beautiful, owing to the number,

[1] For a description of the cave see G. S. Corstorphine, *G. C.*, i., p. 34; a plan of the cave by H. M. Luttman Johnson accompanies the description.

form, and brilliance of the stalactites attached to them. Other caves, the entrance to which is often on the face of cliffs along the sides of the valleys, await exploration in the Cango district. The band of limestone in which the great cave is situated is about 1,800 feet thick, but when traced to the east or west it gradually becomes thinner. The limestone in the Cango beds is crystalline and dark grey in colour and usually contains some magnesium carbonate, but in some localities it is sufficiently pure to yield good lime. Occasionally oolitic beds are met with, and when examined under the microscope these are found to contain organic remains, although no determinable shell has been seen. These are the only traces of fossils hitherto found in the Cango series.

Slates and fine quartzitic grits form a great part of the series. The slates are irregularly cleaved, and no rock of use for roofing has been found amongst them.

The intrusive rocks in the Cango district are nearly all altered to such an extent that the original minerals composing them have been replaced by others. At present the chief components are the fibrous variety of hornblende called uralite, green hornblende, augite, epidote, chlorite, felspar, quartz, calcite, sericite, magnetite, apatite, and brown mica. The greater number of the dykes were originally dolerites without olivine, made up principally of augite and felspar; some contained much hornblende which still remains in the rock. The augite has been mostly altered to uralite, but kernels of the former mineral are still left within the patches of fibrous hornblende. The rock has often an ophitic structure, the felspar crystals lying partly or wholly within the patches of fibrous hornblende derived from augite. The calcite is sometimes sufficiently abundant in the rock to cause it to effervesce like an impure limestone when a drop of dilute acid is put on it. The calcite is often seen to partly replace the large crystals of felspar, but most of it occurs in the ground mass of the rock. It is to be looked upon as one product of decomposition of the lime soda felspar which once formed a large part of the rock. Epidote is often a very abundant constituent, and is probably derived from the lime soda felspar. Little of the original felspar remains, although the outlines of that which has been altered to other minerals can usually be found in thin sections, and in the case of porphyritic crystals the pseudomorphs are easily seen by the naked eye.

Dykes of these altered rocks are fairly numerous in all parts of the Cango district; they are usually only a few feet in width, but are traceable for considerable distances. In the valley of the Nels River in the Eastern Cango there are fifteen dykes in the slates within a distance of two miles, all traversing the rocks parallel with or at a small angle to their strike. In the valley of the river which leaves the Cango through Coetzee's Poort three dykes are seen, the northernmost one is six feet thick, the second over 100 feet, and the southernmost is of much greater size and makes an outcrop nearly a mile in width. This great intrusive mass has been traced for twelve miles along the southern edge of the Cango between Coetzee's and Potgieter's Poorts, forming rather prominent deep red hills (see

Fig. 5). It is a peculiar type of rock, with much hornblende forming ophitic plates enclosing the felspar, the hornblende is colourless and seems to have been formed from augite. The Gamka River, above the Ladismith Road, crosses a dyke of peculiar diabase, in which the rather long crystals of felspar form radiating star-shaped bundles. Beyond a marked hardening of the slates or grits in contact with the thicker dykes, there is little alteration in the sedimentary rocks near them.

The French Hoek Beds.

At French Hoek there is typically developed a series of slates, arkoses, pebbly grits and conglomerates, which appear to be younger than the granite and quartz-porphyry intrusive in the Malmesbury beds but which are older than the Table Mountain series. At the south end of the Midden Berg, on the west side of the village, there is a coarse conglomerate, somewhat sheared, and full of well-worn boulders of quartzites, grits, slates, vein-quartz, quartz-porphyry and granite. It dips at a high angle to the north-west and rests upon quartz-porphyry. Similar conglomerates are seen at the ridge to the south of the village. In several localities the strata in contact with the quartz-porphyry consist of cleaved grits and sheared arkoses. The latter are very like sheared quartz-porphyries, and it is often impossible to detect any clear line of demarcation between the two rocks in the field. The quartz-porphyry and granite appear to have furnished by their disintegration and decomposition a coarse felspathic material which eventually formed beds of arkose; the subsequent folding of the rocks developed a shear structure in the sediments. The grits are always felspathic and contain little pebbles of quartz and sometimes of slate and phyllite.

Similar beds are found between French Hoek and Klapmuts and also on Klapmuts Hill, but they have not been separated from the Malmesbury beds in the course of mapping.

The Ibiquas Series.[1]

In the west of Calvinia and the north-eastern part of Van Rhyn's Dorp there is a group of conglomerates, grits, sandstones, shales and slates covered unconformably by the Table Mountain series of the Bokkeveld Mountain on the east and, in places, by the Nieuwerust series on the west; on the south-western side they are in contact with the Malmesbury beds. In the east the beds have low dips, but towards the west they become more and more disturbed; there is very little, if any, difference between the slates of the Malmesbury and those of the Ibiquas series in the greatly disturbed area where the dips are often westwards at high angles, so there is often a difficulty in laying down the limit between the two series in the absence, or lack of outcrops, of the conglomerates at or near the base of the Ibiquas group. These conglomerates contain pebbles and boulders of limestones, phyllites and other rocks evidently derived from the Malmesbury series as well as of granite, gneiss and quartz-porphyry, so they prove the later age of the series and afford a good horizon for mapping purposes, but the boundary runs through an area where

[1] *G. C.*, v., p. 25, etc.; viii. p. 149; ix. p. 32.

the rocks are obscured by superficial deposits. It is probable that part of the junction is an unconformity; but part of it is certainly either a thrust fault along which the Malmesbury beds have been thrust north-east or eastwards over the younger rocks, or the unconformable junction has been overturned so that the younger rocks now dip towards the older.

Above the conglomerates and grits of the lower part of the series lie slates, sandy shales and sandstones, which are cleaved only in the more highly disturbed area.

The shales and sandstones are met with on the steep escarpment of the Bokkeveld Mountain, and in the Doorn River Valley. They are rather like the shales and sandstones of the Bokkeveld beds, but the thick groups of sandstone beds, so characteristic of the latter, are not found in the Ibiquas series.

Ripple markings are extremely well preserved in many of the sandstones throughout the series, and point to the deposition of the beds in shallow water. Large tracks and castings of some worm-like animal are occasionally abundant, but these are the only fossils known from the series. The nature of the rocks seems very favourable for the preservation of organic remains, and they are more likely to yield recognisable fossils than any other Pre-Cape rocks in the south and west of the Colony. They are unfortunately situated in a district which is thinly populated and difficult to get at. The thickness of the Ibiquas beds must be very considerable; on the face of the Bokkeveld escarpment over 1,500 feet of these beds are exposed, but the base is some distance from the foot of the escarpment, and the highest beds visible lie about fifteen miles to the east, where they are covered by the Dwyka conglomerate. Although the beds are partly repeated by folding between the western and eastern boundaries, their whole thickness must be several thousands of feet.

The northern limit of the beds is a fault, along which they have been let down against the granite and gneiss of Bushmanland. The fault is seen on Ezel Kop Vlakte and Klomp Boomen, two farms west and south-west of Loeries Fontein, but its western course has not been traced. The throw of this fault is not known. As the Ibiquas beds nowhere show any signs of contact metamorphism due to the proximity of the granite underground, and as they contain large quantities of material derived from a granitic region probably not far away from the neighbourhood, the Bushmanland granite may be safely regarded as the older rock. The foliation planes in the gneiss of the Langebergen and the south end of Bushmanland have a nearly east and west strike, and would seem to belong to a much older period than the movements which gave the Ibiquas beds their prevalent north and south folds.

The only intrusive rocks hitherto found in the Ibiquas beds are dykes of dolerite, evidently belonging to the same group of intrusions that form the sheets and dykes in the country occupied by the Karroo formation to the east and south-east.

The section in Fig. 6 illustrates the structure of the Ibiquas beds in the Doorn River Valley. The line of section is so chosen that it runs across the fault on

Klomp Boomen, and also through the Dwyka conglomerate resting upon the Table Mountain sandstone of the Bokkeveld Mountain on the south-west, and upon the granite to the north-east of the Doorn River Valley; but if the section had been drawn along a line a few miles to the south of that chosen, the conglomerate would lie upon the Ibiquas beds.

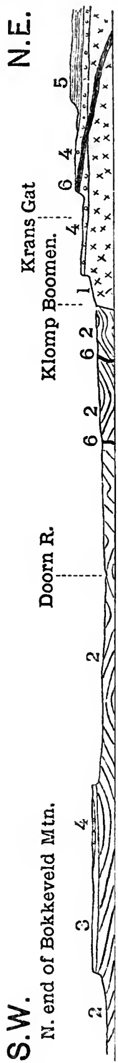


Fig. 6.—Section from the Van Rhyn's Dorp flats to the plateau above Loeries Fontein. Distance 30 miles. Vertical scale $\frac{1}{16}$ in. to 1,000 feet.

1. Granite.
2. Ibiquas series.
3. Table Mountain sandstone.
4. Dwyka series.
5. Ecca series.
6. Intrusive dolerite.

Some reddish shales and sandstones in the Verloren Valley in Piquetberg have been classed with the Ibiquas series on account of the great contrast in lithological character between them and the sericitic slates of the Malmesbury beds with which they are in contact on the farm Wit Drift. They pass unconformably below the Table Mountain sandstone, but the nature of the junction with the Malmesbury beds is not clear, though there is little doubt that it is also an unconformity.

Another group of outcrops that have been referred to the Ibiquas series occurs near Honig Berg in the Piquetberg Division; they consist of red conglomerates with pebbles, up to twenty inches in diameter, of reddish quartzitic rocks like certain beds in the Malmesbury series in the neighbourhood.

It is possible that the Cango, French Hoek and Ibiquas beds belong to one and the same series, but until fossils have been found in them the question must remain undecided. Correlation with the northern Pre-Cape formations is of course still more difficult, and at present the question is scarcely worth discussion.

4. The Nieuwerust Series.[1]

At the north end of the Van Rhyn's Dorp Division there is a group of hills which present an appearance strikingly different from that of the granite hills of the north-western part of that Division and the southern end of Namaqualand. These hills are made of arkose, thin conglomerates, quartzites, and hard shales, over 500 feet thick near Groot Graafwater and nearly as much in the Flamink and Karree Bergen, the ridges between which the main road to Namaqualand passes twelve miles south of Nieuwerust Post Office. The beds take their name from their occurrence near this place.

At several places the arkose, or a conglomerate with an arkose matrix, is seen to rest upon a worn surface of gneiss; the arkose is composed of pieces of felspar and quartz, evidently derived from the Namaqualand granite and gneiss, pebbles of which are at places abundant. Those layers of the rock which have much felspar in them are deeply disintegrated and weathered, but where quartz is present in large proportion the rock

[1] *G. C.*, ix., pp. 35-40.

has become a quartzite by the cementation of the grains by quartz. Some of the quartzites contain numerous grains of felspar, which has been determined under the microscope to be microcline, microperthite, orthoclase and a plagioclase, varieties of felspar that occur in the granitic rocks of north-western Van Rhyn's Dorp. Along the eastern side of Flamink Berg the Ibiquas beds, steeply inclined, pass under the Nieuwerust beds, and the same thing happens at Karree Berg and the hills of Drie Kuil and Spitsberg. The Nieuwerust beds at all these places lie at comparatively low angles, and were evidently deposited unconformably upon both the gneiss and the Ibiquas beds.

Although the Nieuwerust beds are usually gently inclined, for their dip rarely reaches 20°, they have been affected by a group of faults with northerly and north-westerly trend. The downthrow of these faults is always on the east, and the maximum difference in level between the two sides of any one of them is probably less than 500 feet.

This area was also affected by faults previously to the deposition of the Nieuwerust beds; for the Ibiquas group is faulted down against the granitic rocks and the Malmesbury series, and these faulted junctions pass under the Nieuwerust beds without apparently affecting them. In the case of these faults also, the relatively depressed area is on the east, but the faults are probably planes of thrust, along which rocks have been pushed eastward over the younger formation. Two small outliers of the Nieuwerust beds occur on Slag Kop near Groot Klip in the north-west of Van Rhyn's Dorp.

The Nieuwerust beds cannot yet be correlated with any other formation, though one is inclined to suspect that intervening links will connect them with the little-known quartzites first described by Wyley from the country immediately south of the Orange River in Little Namaqualand, and mapped by him as "Table Mountain Sandstone,"[1] and subsequently coloured in as Witteberg beds by E. J. Dunn.[2]

It is possible that these beds represent part of the nearly horizontal arenaceous rocks in German South-West Africa and the Zwart Modder series of Gordonia, but correlation with the rocks of Griqualand West will be difficult.

[1] Geological Map of the Cape of Good Hope by A. Wyley dated 1859, exhibited in the South African Museum.

[2] E. J. Dunn. Geological Sketch Map of South Africa, Melbourne, 1887. Professor Schwarz in *G. M.*, 1908, p. 425, suggests their correlation with the Nieuwerust series.

CHAPTER III.

THE PRE-CAPE ROCKS OF THE NORTH OF THE COLONY.

1. The Kheis Series.

The rocks of this series are known to form a broad band running south-south-east from the neighbourhood of Upington into the Prieska Division. Near the Orange River west of Ezel Rand there is a deflection towards the north and north-north-east which carries a large part of the group into the Kalahari north of Kheis.

So far as these rocks are known at present they have little resemblance to the Malmesbury series of the south-west, but it is probable that the granite of Namaqualand is intrusive in the Malmesbury beds in the south and in the Kheis beds in the north. It remains to be proved, however, whether the great north-western mass is of one age throughout.

The series is divided into two sub-groups founded on lithological characters and stratigraphical position. The supposed lower group, the Marydale beds, occurs on the north-eastern side of the ranges made of the supposed upper or Kaaien beds, and fragments of it may perhaps also be recognised in certain highly metamorphosed rocks found in the gneiss on the south-western side of the ranges.

The Marydale beds.[1]

These beds include lavas, tuffs, quartzites, arkose, limestone, and schists of various kinds. They are found dipping under the Kaaien beds between Brul Pan and Stuurmans Puts in Prieska, and on this band the village of Marydale stands. At Blaauw Puts again they occupy a similar position, and here there is a remarkable development of limestone and chert interbedded with altered lavas. Elsewhere they form belts surrounded by gneiss and lying parallel to the foliation planes of that rock; veins of gneiss and granite are abundant in these isolated masses.

The most striking features in the sub-group are the intensity of the metamorphic effects in the lavas and the presence of quartzites containing much magnetite; the latter rocks form prominent ridges and kopjes in the Prieska Division between the Doornbergen and the Kaaien hills, particularly the Groot Modder Fontein ridge and the Zwart Kops. These magnetic quartzites contain peculiar minerals of the amphibole group, but crocidolite and its allies have not been found in them.

The lavas are of various composition from altered rhyolites to rocks probably at least as basic as olivine-basalts. The acid rocks have not suffered very great change, but the basic varieties, in some of which remnants of the original structure are visible, form a series from epidiorites to hornblende-schists and garnetiferous hornblende-granulites. Amygdaloidal structure is occasionally seen in all these rocks; in the more basic

[1] *G. C.*, xiv.

kinds of granulites consisting of dark green hornblende, blue augite, labradorite, sphene, and sometimes garnet and epidote, the presence of the coarsely granular quartz in the sharply defined lenticles that were once steam-holes, gives the rock a very characteristic appearance. The markedly schistose rocks are usually made of quartz, felspar, tremolite, actinolite, a much darker green hornblende, epidote, sphene and magnetite with or without garnet. As the felspar decreases in amount epidote increases, and garnet also. There is no sharp line of demarcation between such rocks and those with a granulitic structure, but in the granulites the hornblende is always actinolite or a much darker variety. The blue augite is confined to the granulites and does not occur in the markedly schistose rocks; to the north-east of the Kaaien hills the augite is not deeply coloured, though colourless varieties are very rare; in the isolated patches of granulites south-west of these hills the augite is more highly coloured. In these western rocks, however, no amygdales have been seen, and their relationship to the Marydale beds is uncertain.

In both the Marydale and the Kaaien beds there are bands of grey granulite, often with the mineral composition of gneiss but grading into almost pure quartzite on the one hand and into hornblende-granulite on the other; they sometimes contain cyanite, staurolite, and sillimanite. It seems probable that much of this grey granulite was of sedimentary origin.

Though there is much doubt as to the original nature of many rocks included in the Marydale beds, it is certain that they are partly of sedimentary and partly of volcanic origin, and that they have been invaded by granite and sheared during, and subsequently to, the intrusion. The variety of schists and granulites produced by the changes due to the influence of the granite and pressure indicates original differences in composition; for example, the abundance of garnet and epidote in a rock that was evidently a lava shows that the rock had lost much of its alkalis before it was altered. It is very probable that the transference of felspathic substance from the granite to the rocks invaded is the cause of the difficulty in the delimitation of the quartzites and granulitic gneiss.

The whole thickness of the Marydale beds may not be much more than 1,500 feet, though in some localities repetition of similar beds by faulting and folding allows the formation to occupy a belt five miles wide.

The resemblance of the Marydale beds to the Kraaipan formation is extremely close, though the proportion of banded ironstones and cherts to volcanic rocks is greater in the latter. The Marydale beds have been invaded by granite, but the Kraaipan formation appears to be younger than the Bechuanaland granite. It is important to note, however, that there are quartz-felspar grits in the Marydale beds and that the Kaaien beds were evidently derived from granitic rocks, so although the Kheis series were invaded by the granite of Prieska and Upington they, like the Kraaipan formation, may be younger than the Bechuanaland granite.

In the Marydale beds there are some intrusions of serpentine older than the granite, for example at Zwartkop, Uitspansberg and Prieska Poort. The rocks are very much altered and sometimes contain much tremolite and talc. At Zoet Vlei there are veins of tremolite ("asbestos") and actinolite in altered basic and ultrabasic rocks.

The Kaaien Beds.

The Kaaien beds[1] consist of quartz schists, mica schists, quartzites, and grey granulites; near Kheis there are also some less metamorphosed gritty beds resembling rocks in the Malmesbury beds of the south-west. No conglomerates have been found in these beds.

The northernmost locality at which the Kaaien beds have been recognised is the neighbourhood of Kuie Pan in the extreme west of Kuruman Division, where quartz and mica-schists with a general N. 10° W. strike form a group of outcrops surrounded by red sand. Similar rocks occur at Malanie and Gamotep Pans farther south, and again at Scheurberg (strike N. 20° W.), where they make a remarkable rugged mountain, the peaks of which are strongly contrasted in their outlines to the flat topped or rounded summits of the ranges composed of the massive grits and quartzites of the Matsap series in the same region.

The Kaaien beds are frequently exposed along the right bank of the Orange River from Upington to just below the Poort through the Langebergen, and on the left bank they make a nearly continuous range of hills stretching from near Upington south-eastwards for 125

[1] *G. C.*, iv., p. 73; xiii., p. 15; xiv. The name Kaaien beds was first introduced in *G. C.*, xiv.

miles to Jonker Water in Prieska, where they pass under the Dwyka. Throughout their length the Kaaien beds in these hills seem to be flanked on the south-western side by gneiss, but between the gneiss and the typical quartzite or quartz-schist there is often a zone of schists and gneissose rocks, some of which are mainly composed of quartz while others approach gneiss in their composition; it is probable that these intermediate rocks have been formed by the addition of granitic material to the sediments. Similar mixed rocks have been observed on the north-east flank of the hills and also round the granite masses within them.

The Kaaien beds have been invaded by both large masses and small veins of granite, and also by rocks that have been converted into hornblende-schists.

The thickness of these beds must be considerable, though owing to folding and faulting, and to the presence of great intrusive masses of gneiss, no attempt to estimate it would be of service at present. The gradual narrowing of the main belt occupied by these beds as it is followed south-eastwards is probably due to the north-west inclination of the axes of the folds and to the fact that the present surface passes obliquely through this folded mass and the gneiss which surrounds it.

2. The Kraaipan Formation.

In Mafeking and Vryburg there is a peculiar formation composed principally of banded magnetic quartzites, cherts and jaspers, sericite-, chlorite-, and calcareous schists, hornblende schist, serpentine, diabase and quartz-porphyry.

The beds have been intensely folded and considerably faulted, and they occur as narrow strips seldom more than two miles wide, flanked on either side by granite and gneiss. In Mafeking there are three of these schist belts with a general north and south strike; one passes through Mosita, one through Pitsani and Kraaipan (extending southwards into the Transvaal and northwards into the Protectorate), and one is at Madibi. This formation is much older than the Ventersdorp system, for rocks belonging to the latter rest upon the steeply dipping schists in several localities, and contain boulders derived from them.

The rocks resemble the beds of the Swaziland system of the Transvaal but they cannot as yet be correlated with that formation, for while the "old granite" of the Transvaal is intrusive in the latter, the granite and gneiss of Mafeking appear to be much older than the Kraaipan formation.

Junctions with the granite are rarely seen owing to the thick mantle of red sand, but the few observed contacts show either a normal unconformable junction or a faulted contact, and no veins of granite have yet been found traversing this formation.

The best sections are to be seen at Kraaipan, where the junction is visible in a cutting along the railway. The whole formation dips eastward at a high angle and the granite is brought up again on the east by a large fault. On Wodehouse Kraal the upward succession is as follows: (1) a zone of massive magnetic quartzites, (2) a zone of light-coloured cherts, chlorite slate, diabase, etc. The softer beds are rarely seen except in artificial openings, hence the proportion of magnetic quartzite and chert is apt to be overestimated.

The thickness of this formation here, even at the very lowest estimate, cannot be less than 10,000 feet, while the highest beds visible are faulted against the granite.

At Madibi the rocks are thinner bedded and consist of alternations of magnetic quartzite and sericite-, chlorite-, and calcareous-schist.

At Pitsani and Mosita the proportion of volcanic material increases, and the magnetic quartzites and cherts form thick bands alternating with great thicknesses of diabasic lava and sometimes diabase breccias and tuffs, quartz-porphyries, grits and slates.

Where the Setlagoli River cuts through the western belt there are four great zones of diabase and the interbedded sedimentaries prove to be representatives of those seen in the central belt; the lowest is composed of magnetic quartzites, the second of chert and jasper, and the third is a series of cherts and quartzites. A thick zone of diabase accompanied by some quartz-porphyry intervenes between the lowest magnetic quartzite and the granite; this is well seen both at Pitsani and Mosita.

At the last-named locality the junction of the diabase and granite is clearly exposed and there is no evidence of the latter rock being intrusive. The thickness of the formation just north of Mosita cannot be less than 10,000 feet, of which fully two-thirds must be of volcanic origin.

The strata appear to have been subjected to more intense metamorphism towards the south-east, and the chloritic and hornblendic schists in that area are evidently the equivalents of the diabases and diabasic tuffs seen to the north-west. The rocks have been much fractured and veined by quartz, the veins being of different ages. The older quartz veins have been contorted and granulitised by subsequent earth-movement. Gold has been found in several of these veins, notably at Madibi and on Wodehouse Kraal. In the former locality the vein stuff consists of quartz, chlorite, pyrites and pyrrhotine, and it fills a fissure traversing the chloritic schist. The auriferous reefs at Abelskop and Goudplaats in the South-Western Transvaal appear to traverse rocks belonging to the Kraaipan formation also.

Small patches of a magnetic quartzite are seen north and north-west of Vryburg, while a large band of magnetic quartzites, slates and interbedded quartz-porphyries strikes east and west a little north of Takoon.

The question of the relationship of the Kraaipan formation to the Kheis series has been discussed on a previous page.

3. The Wilgenhout Drift Series.[1]

Near Wilgenhout Drift on the Orange River above Upington there is a group of rocks not yet correlated with any other formation. The series consists of sheared diabase lavas, tuffs, quartzites, slates, crystalline limestones, quartz-porphyries, and a few bands of conglomerate with quartz-schist pebbles in them; possibly also some ferruginous cherts are part of the series.

These rocks have been examined in a strip of country ten miles long on the right bank of the river,

[1] *G. C.*, xii., pp. 35-42.

where they are separated by faults from the Kaaien beds to the east and from the Koras beds on the west. And intrusions of a glassy doleritic rock have risen along the faults; on the north-east they are apparently overlain unconformably by beds which have been assigned to the Matsap series.

The sheared diabase lavas are often amygdaloidal, but with them are some sheared intrusions of diabase which also penetrate slates of sedimentary origin, and it is difficult to separate the lavas from the intrusive rocks. The quartzites are dark-coloured reddish rocks. In the north-eastern part of Upington Commonage there is an isolated patch of dark red quartzite with diabase below it resting unconformably upon the Kaaien beds; so if these beds belong to the Wilgenhout Drift series the latter must be younger than the Kaaien beds.

[Recent work along the south bank of the river shows that these beds overlie and partake in the folding of the Kaaien quartzites. They are cut by granite veins, and may ultimately prove to be the uppermost portion of the Kheis series.]

The Wilgenhout Drift series must be over 3,000 feet thick.

4. The Granite and Gneiss.

In Bechuanaland granite occupies an area of several thousand square miles, though over wide stretches the rock is only seen in wells; now and again the granite forms low ridges, as at Kraaipan, but usually it only crops out occasionally along the river beds and in pans. The granite of this district is usually a pinkish or grey medium grained rock containing microcline and muscovite or biotite; hornblende and augite are seldom present. The structure varies from massive to gneissose, and there are frequently alternations of the two types. The gneissose arrangement is not the result of earth-movements subsequent to the consolidation of the rock, for autoclastic structures are rare; the parallelism must have been caused by movements in the magma before and during its consolidation. Porphyritic varieties are infrequent. Pegmatites and quartz veins, on the other hand, are abundant.

In the Mafeking Division the granite contains inclusions of various schistose and granulitic rocks which represent portions of an older formation. Those inclusions are rich in hornblende and sometimes contain augite, epidote, and garnet. They recall fragments of the Marydale (Kheis) beds enclosed by the granite of Prieska, and are probably of the same nature.

In Prieska, Kenhardt and Gordonia there are large tracts of granite and gneiss west of the hills made of the Transvaal formation; small areas are found to the east of these rocks as well, in the valleys tributary to the Vaal River and the inlier crossed by the Brak River at T'Kuip. As in the case of the northern districts, the granite is often covered with sand and rarely forms ridges. A prominent little "tor" occurs just outside Prieska Poort and another is the Water Kop on Jackals Water; near Upington and at Put Zonder Water there are kopjes made of huge rounded boulders, the kernels left by the weathering of the granite along joints. These granites contain microcline in considerable quantities and are often gneissose; they resemble the Bechuanaland rock. On the south-west flank of the Doornbergen the granite is traversed by planes of shear, and in places it has been converted into a flaggy rock scarcely distinguishable from a fine-grained quartzite. The minerals have broken down to form a granular ground mass containing occasional "eyes" of felspar and quartz; these crushed bands of rock can be called mylonites. At Prieska Poort glaucophane and epidote have developed in such rocks. This structure was of course given to the rock long after its consolidation, but the gneissose structure was produced before it became solid, and though the two kinds of structure have parallel strikes there is often considerable divergence between them in places.

As mentioned in connection with the Kheis series, the granite has invaded the latter, and peculiar rocks have been produced by the mixing of the granitic material with the quartzose sediments of the Kaaien beds on the one hand and with the basic lavas of the Marydale beds on the other. As a result there are streaky rocks, usually with granulitic structure, varying in composition from extremely siliceous types to basic, and often containing garnet. In many places it is difficult to determine the boundary of the intrusive rock.

Pegmatites are very frequently seen, especially in the formations invaded, and in the south-eastern corner of Kenhardt the crystals are of such gigantic dimensions that one can walk for many yards over continuous masses of white microcline felspar. Graphic granite is abundant. These pegmatites contain muscovite and occasionally garnet and hæmatite. Tourmaline is of rare occurrence; it is found in quartz veins in the Marydale beds west of Uitspansberg, but it is reported to be plentiful in the north-west of Kenhardt.

CHAPTER IV.

THE PRE-CAPE ROCKS OF THE NORTH (*continued*).

1. The Ventersdorp System.

In Cape Colony and also in the south-western part of the Transvaal the Black Reef series usually lies unconformably upon dark-coloured volcanic rocks. The latter were first described by Stow[1] under the name of "The amygdaloidal rocks of Pniel". These lavas and the associated sedimentary beds usually rest with marked unconformity on very much older rocks, but in places there are intervening groups largely made of either acid or basic lavas, separated from each other and from the Pniels by unconformities. These volcanic groups together make up the Ventersdorp system,[2] which is thus subdivided in downward succession:—

C. The Pniel series.
B. The Kuip series.
A. The Zoetlief series.

The unconformities between these three series are of great importance locally, but none is so pronounced as that at the base of the lowest group in any given

[1] Stow, *Q. J. G. S.*, xxx., Pl. xxxv.

[2] Also called the Vaal River system by Molengraaff, *Geology of the Transvaal*, 1904; "Ventersdorp" system was introduced by Hatch, *T. G. S. S. A.*, 1904, vi., p. 95.

locality. The unconformity between the Black Reef series and the rocks of the Ventersdorp system seems to be of a similar nature to those within the latter, and lavas very like those of the Pniel series occur near the base of the Transvaal system in Vryburg. Though these facts might be held to justify the inclusion of the Ventersdorp beds in the Transvaal system, the latter as ordinarily defined has a far wider distribution in a uniform state than it would have were the meaning of the term altered.

Another group of rocks, the Koras series, is for convenience placed in this system, though its true position is not known.

A. The Zoetlief Series.[1]

The characteristic feature of the oldest member of the Ventersdorp system is the predominance of quartz-porphyries (devitrified rhyolites), but at places there is a small thickness of sedimentary rocks at the base and also above the lavas.

The acid lavas are often amygdaloidal. They are usually much altered, especially by the replacement of the felspar by silica. They vary in colour from pale grey or pink to dark green and black. The quartz crystals are more or less corroded; crystals of felspar are often very plentiful. In many of the lavas no ferro-magnesian constituent is seen, but in others there are

[1] *G. C.*, x., p. 235; xi., p. 14 and 93; xii., p. 50 and 164. Also R. H. Rastall, *Rep. S. A. A. A. S.* for 1905 and 1906, p. 275, "Acid Volcanic Series"; and Schwarz, *Rec. Albany Museum*, 1907, vol. ii., p. 34. The "Beervley Volcanic Series" of *G. C.*, iv., p. 86, and of the first edition have been found to be part of this group.

crystals of enstatite, or pseudomorphs after that mineral. The more basic lavas are andesites. The matrix of the devitrified rhyolites sometimes shows perlitic cracks, a feature characteristic of glassy lavas, and flow structure is often well developed. The largest area of these beds is in the Vryburg division, and extends from near the farm England to Zoetlief, a distance of twenty-eight miles. Arkose and quartzitic flagstones occur at the base of the series in this area, though they are only seen in wells; the lavas are porphyries of various kinds representing rhyolites, trachytes, and andesites. Above the lavas there are again sedimentary rocks, acid tuffs and breccias, quartzites, flagstones, shales, thin limestones and chert, with which lava-flows are occasionally interbedded. The flagstones are often finely ripple-marked. The flagstones of Zoetlief and the Groot Chwaing inlier are used for fencing poles and building purposes.

Inliers, surrounded by Pniel lavas and sand, of ripple-marked flagstones and shales succeeded by acid lavas occur at Groot Chwaing, Karree Bult, and Schat Kist in Vryburg. On the Motiton Reserve there is an outlier of these rocks nine miles long and three wide in the granite area; the lowest beds seen are grey flagstones and they are overlain by quartz-porphyries.

Five miles north of Mafeking there is a small area of Zoetlief lavas, tuffs, cherts and quartzites, overlain unconformably by Pniel beds.

The working of the mines at Kimberley has proved the presence of 1,300 feet of Zoetlief beds lying nearly horizontally on an old granite surface. In the Kimberley mine some 300 feet of sedimentary rocks, including conglomerates with pebbles of granitic rocks, quartzites, and quartz, lie below the quartz porphyries, but at the De Beers mine the latter rest directly on the granite. Farther south, on the Riet River west of Modder River Station, amongst the volcanic rocks of the Pniel series inliers of the acid lavas occur, while two more project through the Dwyka near Klokfontein Siding. Between Strydenburg and Omdraai's Vlei there are inliers surrounded by Dwyka tillite at Wonderdraai and at several places near Beer Vlei; in the T'Kuip hills 300 feet of arkose, conglomerates and breccias lie on the granite, but they are overlapped towards the south by some 500 feet of the overlying acid lavas, which are in turn covered unconformably by the Kuip series. A small hillock of the quartz-porphyries rises from the granite on Maritz Dam; the rock is banded, and the bands are due to movement in the lava when it was liquid; they dip inwards towards the longer axis of the hillock, which probably marks the site of a volcanic neck.

Acid porphyries lying in the very much sheared belt between Uitspansberg and Geelbeck's Dam in Prieska may belong to the Zoetlief series.

B. The Kuip Series.[1]

In the T'Kuip hills near Omdraai's Vlei a group of some 1,500 feet of diabase lavas and sedimentary rocks lies between the Zoetlief beds and the Pniels, with an unconformity both above and below. The lavas rest

[1] *G. C.*, xii., p. 168.

directly on the rhyolites of the lower group in the north and middle parts of the hills, but at the south end they overlap the Zoetlief beds and lie on the granite.

The Kuip lavas are greenish-blue rocks, usually amygdaloidal, and just like the more basic lavas of the Pniel series ; there is little or no volcanic breccia.

The sedimentary rocks are principally arkoses ; they are conglomeratic in places and contain pebbles, some of which have been derived from the Zoetlief lavas ; there are also layers of flagstones, limestones and cherts. Two small patches of this formation occur on Maritz Dam.

The Kuip series has not been recognised elsewhere in the Colony.

C. The Pniel Series.[1]

These beds which cover a wide area east of the Langebergen in the north of the Colony, consist mainly of blue-green diabasic lavas and sedimentary rocks, often with much greenish *débris* in them. The series varies greatly in thickness, but, where best developed, the lower portion consists of sedimentary rocks and the upper chiefly of lavas.

The sedimentary rocks comprise conglomerates, arkoses, quartzites, flagstones, and (around Beer Vlei) limestones and chert. They were evidently deposited upon an uneven floor, and their variation in thickness is partly due to this circumstance. The conglomerates

[1] Stow, *Q. J. G. S.*, xxx. ; *G. C.*, x., pp. 149, 249, (Diabase formation) ; xi., pp. 15-97 ; xii., pp. 51, 170 ; xiii. ; Rastall, *Rep. S. A. A. A. S.* for 1905 and 1906, p. 272.

are well developed in the Pokwani and Taungs anticline, near Mafeking, and again west of Setlagoli, at Botman's Poort on the Transvaal border, at Kimberley and at Wit Vlei in Prieska; they contain boulders of many of the older rocks including the Zoetlief quartz-porphyries. The quartzites are pale-coloured rocks, often ripple-marked, and they may reach a thickness of over 600 feet; some of them are felspathic, and the felspar fragments are such as would be derived from a granite country.

The transition from the mainly sedimentary part of the series to the volcanic beds is sometimes gradual, for lavas and tuffs are found interbedded with the quartzites, the latter becoming less frequent in the higher part of the group.

The lavas are chiefly blue or green diabases weathering with a thin, reddish-brown crust. They are frequently amygdaloidal; the steam-holes are filled with chalcedony, calcite or chlorite. Some of the chalcedony amygdales have a bright pink or a red colour. In some localities, as in the Kimberley mine and on the road to Schmidt's Drift, the amygdales in some layers are very much elongated, they are arranged parallel to each other and perpendicularly, or nearly so, to the base of the lava-flow. Another peculiarity, seen at Barkly West, is the occurrence of vertical cylindrical columns of vesicular lava up to six inches in diameter, in compact lava of the same composition.[1]

Plagioclase felspar, chiefly oligoclase and andesine, and augite seem to have been the chief constituents of the

[1] Du Toit, *G. M.*, 1907, p. 13.

lavas, and the matrix in many cases was glassy, but in some there is much quartz and quartz-felspar micropegmatite in the ground mass. The rocks have generally been much altered, the augite being replaced by uralitic hornblende and the felspar by quartz, calcite and epidote. The ilmenite of the original rock has been changed into leucoxene. Porphyritic lavas with rather large felspar crystals sometimes occur in the higher part of the series. Two analyses of the diabase from the Vaal River and the Kimberley mine, with 49·5 and 45·6 per cent. of silica respectively, are given by De Launay.[1] In many places the rock seems to have received an addition of silica, now in the form of either opal or chalcedony.

More acid lavas, andesites and quartz-porphyries, are found in the higher parts of the series along the Vaal River below Barkly West. Coarse breccias and fine-grained tuffs are often interbedded with the lavas; in Hopetown and Herbert a band, from 50 to 100 feet thick, of coarse volcanic breccia, with many fragments of a more acid variety of lava than the usual diabase, covers a wide area and lies immediately above the quartzites of the lower part of the series.

The largest area occupied by the Pniel series, though over parts of it they are thinly covered by later rocks, is that of the Dry Harts, Harts and Vaal River Valleys.[2] West of Vryburg they are met with at Takoon, where they form a narrow belt consisting of a thin layer of lavas lying between the Black Reef and the granite;

[1] *Les Diamants du Cap*, Paris, 1897, p. 109.

[2] See Sheets 41, 42, 46, 50 of the Geol. Map of Cape Colony.

they thicken eastwards by the coming in of more lavas and green flagstones. For a distance of some thirty miles north-west of Vryburg they rest upon the Zoetlief lavas and overlap them at each end. The Pniel beds stretch continuously from Takoon to the Transvaal border near Vryburg, a distance of nearly eighty miles.

North of Vryburg the belt is thirty-seven miles wide, and the rocks again rest upon granite and the Kraaipan series. The older rocks come to the surface in the drainage basin of the Molopo south of Maretsani, but between Setlagoli and Mosita an outlier consisting of conglomerates and grits followed by lavas and breccias has been preserved in a synclinal fold. Pniel beds, consisting of both breccias and lavas, again occupy a large tract of country from Maretsani to beyond Mafeking, while the town itself is built on a massive coarse conglomerate at the base of the formation.

A small patch of lavas and green flagstones has been found near Morokwen.

Immediately south of Vryburg the Transvaal formation and the Dwyka cover the volcanic rocks for some distance, but the latter appear on the Transvaal border and extend without a break in a south-south-westerly direction past Barkly West. South of Barkly West they are covered over wide areas by the Dwyka, which still partly fills the Pre-Karroo valley now being re-excavated by the Harts and Vaal Rivers. The series in this area is bent into a very low anticline, trending south-south-west; at Kimberley it reaches a thickness of nearly 1,580 feet, including some 700 feet of quartzite at the base. The rocks are occasionally exposed along the same strike as far south as Maritz Dam and evidently underlie the greater part of Herbert and Hopetown. On the west side of the Transvaal formation in Prieska and Hay the Pniel series has been much crushed, folded and faulted, but it extends almost continuously from Uitspansberg to Zeekoebaart. Towards the south-east it has been cut out by faults on the flank of the Doornbergen, but from Uitspansberg to Kameelboom a thin belt of lavas, often very much sheared, lies between the granite and some member of the Transvaal system. At Wit Vlei there is a coarse conglomerate with boulders of acid lava, but conglomerates and other sedimentary rocks are not frequent in the Prieska area. Towards Ezel Rand the area of Pniel beds widens out greatly, and some breccias containing granite fragments lie at or near the base of the series on the west side. The Pniel beds have been much sheared in Prieska, especially near their junction with the granite. In places they have been converted into slaty phyllites, in which the amygdales form "eyes," and at the granite contact there is a zone of sheared breccia probably produced in places by earth-movements; near Schalks Puts large masses of granite are found in the lavas, showing sheared contacts, and the lava occurs similarly in the granite. The contact zone shows no sign of modification due to igneous intrusion.

D. The Koras Series.[1]

About thirty-five miles above Upington the Orange River enters an area made of red rocks, lavas, conglo-

[1] Described in *G. C.*, xii., p. 52.

merates and sandstones, the position of which in the stratigraphical series is doubtful. They are called the Koras series from their occurrence on the farm of that name. Only the outcrops on the right bank of the river have as yet been examined, but the series certainly extends over part of the Kenhardt district. The length of the largest area of this formation traversed by the river is fourteen miles; towards the north the Koras rocks disappear under the sand of the Kalahari. A smaller area on Kameel Poort and Rooi Kopjes covers some ten square miles.

The eastern limit of the Koras beds is formed partly by a fault with a northerly course, along which they are thrown down against the Wilgenhout Drift beds, and partly by an intrusion of enstatite-diabase which has a devitrified glassy base. This rock has risen along the fault, and a similar intrusion has taken place along another fault with a north-north-west course limiting the outcrops on Koras, where the sediments of the Koras group have been considerably altered by the diabase. The western fault has a downthrow to the north-east, and the Koras beds have been thrown against the Kheis quartzites.

The Kameel Poort and Rooi Kopjes outlier rests upon the steeply inclined Kheis beds unconformably.

The Koras beds, though affected by these faults and intrusions, have been disturbed to a very much less extent than the Wilgenhout Drift and Kheis beds, and at a distance from the diabase they have a younger appearance than the other Pre-Karroo rocks in the north.

The lower part of the series consists of lavas and tuffs, with which quartz-porphyries of a peculiar type are intercalated on Leeuw Draai. The lavas are basic pyroxene-andesites with much devitrified glass; usually the larger crystals, both felspars and pyroxenes, are replaced by alteration products, of which epidote is the most conspicuous. Augite and enstatite are present, but the latter is always altered. A rather characteristic feature of the lavas and also of the diabases along the boundary faults, as seen under the microscope, is the presence of magnetite crystals arranged in long strings in the glassy base. The lavas are markedly amygdaloidal; the amygdales are of epidote or chalcedony, or both together, and the bright green colour of the epidote amygdales contrasts strongly with the red matrix, giving a remarkable appearance to some of the lavas.

Tuffs and breccias are interbedded with the flows.

The intercalated quartz-porphyries are red rocks containing corroded quartz and felspar crystals, also felspar crystals with which quartz is intergrown; small but well-shaped crystals of a pyroxene have been replaced by chlorite and epidote. The relation of these porphyries to the lavas is uncertain; they may be intercalated flows or intrusions; if they are intrusions they reached their present position before the conglomerates of the Koras series were formed, for the latter contain pebbles of both amygdaloid and porphyry.

The conglomerates, sandstones and quartzites of the upper part of the Koras series are separated by an unconformity from the volcanic rocks. The pebbles in the conglomerates are chiefly of quartzites and schists from the Kheis series, granites and lavas and porphyries from the lower beds. They are often closely packed, and the pebbles in contact with each other are fractured and indented.

The finer grained sedimentary rocks are felspathic sandstones and quartzites of a dark red colour; they are thick bedded and remarkably free from current-bedding and laminæ. They must be several hundred feet thick, but neither the thickness of the beds nor that of the lavas has been measured.

Though the Koras beds on the whole resemble the Pniel series more than any other group there are considerable differences between them, especially that due to the red colour of the Koras beds. This character is so uniformly shown by the sediments that it was probably an original feature.

The beds have been placed in the Ventersdorp system, but they may be of much later date, later even than the Matsap series.

The country they occupy has a very different appearance from that of the surrounding older beds. The lavas give rise to low rounded hills which contrast strongly with the sharper forms assumed by the steeply dipping Kheis and Wilgenhout Drift beds.

2. The Transvaal System.[1]

In the country north of the Karroo, where the Karroo formation has been removed by denudation over wide areas, a large part of the surface is occupied by the

[1] Also called the Potchefstroom (Hatch and Corstorphine), and the Lydenburg (Dunn and Passarge) System.

three members of the Transvaal system. The three groups are found over some 23,000 square miles east of the Langberg-Korannaberg Range.

They have not been definitely recognised west of this range nor in the south of the Colony, in spite of the assumption often made that the dolomitic rocks of the Cango series must belong to the same group as those of the Campbell Rand series.

Though a few travellers, such as Lichtenstein and Burchell, briefly described some of the characteristics of this group of rocks a hundred years ago and more, the first attempt at a systematic investigation was made by G. W. Stow,[1] who, in spite of an error by which he confounded the volcanic group high up in this system with the Pniel volcanic beds lying unconformably below it, made a great advance in the knowledge of the geology of Griqualand West.

The system, as developed in Cape Colony, is divided up into three series:—

Griqua Town series:
- Upper Griqua Town beds.
- Middle Griqua Town or Ongeluk beds.
- Lower Griqua Town beds.

Campbell Rand series.

Black Reef series.

A. The Black Reef Series.

The Black Reef series, mainly a sandstone group with subordinate beds of conglomerate, is taken to be the base of the system, as there is undoubtedly an un-

[1] *Q. J. G. S.*, xxx., 1870, p. 581.

conformity below it, but this unconformity is of less importance than those at the base of the Ventersdorp and Waterberg systems in Cape Colony.

It gets its name from a conglomerate which occurs in it in the Transvaal,[1] where it was first definitely separated from the overlying Dolomite formation.

In Cape Colony[2] the series consists of usually light-coloured quartzites, grits, gritty shales, conglomerates and limestones, with lavas and green volcanic ash-beds near Vryburg. Where it rests directly on granite, as is the case in the Mashowing Valley at and below Motiton, there are several feet of rock made of granite *débris* at the base. There is a rather gradual decrease in the amount of felspar present from the lowest layers upwards, and it is at places difficult or impossible to see where the old granite surface ends, for the granite is weathered as well as the arkose. Where the series rests on the Pniel beds at Takoon the lowest beds are quartzitic grits with little felspar. In some localities, such as the neighbourhood of Vryburg, the quartzites and flagstones have a darker colour than usual, owing to their containing much dark-coloured material derived from the Pniel lavas. The quartzites are often current bedded, and both they and the flagstones, thin-bedded somewhat argillaceous rocks, frequently have very well-developed ripple marks on their surfaces, a feature

[1] Penning, *Q. J. G. S.*, xlvi., p. 456. The name Black Reef series is most inappropriate as applied to the group of beds commonly known by it, as indeed are most group names first derived from some local peculiarity and extended to contemporaneously formed rocks over a wide area.

[2] For details of the Black Reef series in Cape Colony see Holmes, *T. G. S. S. A.*, vii., 130. *G. C.*, x., 245; xi., 19, 105; xii., 59, 174; xiii., 83.

which is particularly characteristic of this series throughout its known extent in Cape Colony. In places dark-coloured cherts containing rhombohedra of carbonate of iron are associated with the quartzites, *e.g.*, Schmidt's Drift and Klip Fontein near Prieska. The conglomerates are irregularly distributed and individual beds can rarely be followed far. The pebbles are of quartz, chert, agate or chalcedony, granite, slaty rocks, lavas from the Pniel and older volcanic beds, and occasionally schistose rocks.

The limestones and calcareous grits are just like many beds in the Campbell Rand series. They usually occur near the upper limit of the series, but in Prieska there is a well-marked band of them near the base.

Between Zwart Fontein and Geluk in Vryburg a band of argillaceous sandstones and ferruginous cherty rocks, the latter very like some of the beds in the Griqua Town series, occurs near the top of the Black Reef series. They give rise to a low ridge about twelve miles long called the Zwart Rand.

The volcanic rocks found in the Black Reef series near Vryburg are blue amygdaloidal lavas and fine-grained flags of the same kind as many rocks in the underlying Pniel group. They occur some fifty feet below the top of the Black Reef quartzite near Vryburg, and again between the latter and the bulk of the Campbell Rand limestones at Takwanen and other places west of Vryburg; in the latter case they are separated from the quartzites by a few feet of limestone. These volcanics are also present on the Transvaal border near Mafeking.

The Black Reef beds are found wherever the strata lying between the great Campbell Rand limestone formation and the older rocks are exposed. In the country north of the Mashowing, and also on the Transvaal border near Mafeking, the series is only some thirty feet thick, but in the Vryburg district and in Griqualand West it is from 150 to 300 feet thick, and in Prieska it is probably thicker still.

Along the Mashowing Valley and to the east as far as Vryburg the series usually makes a prominent escarpment, and even where the rocks are covered with sand a distinct rise in the ground marks their position. From Vryburg southwards the Black Reef series only appears occasionally from beneath the Karroo formation in the Harts-Vaal Valley, and in many places there is evidence that denudation in this area removed the beds over wide areas in Dwyka or Pre-Dwyka times, for the Karroo formation often rests directly on the Ventersdorp or older rocks. In this valley the formation includes a good deal of shale. In Prieska again the Black Reef series is frequently exposed for considerable distances in the highly disturbed belt along the south-western flank of the hills made of the Griqua Town beds.

B. The Campbell Rand Series.[1]

This group of rocks, one of the most important in the north of the Colony owing to the large area it covers, is named from the great escarpment which stretches south

[1] For descriptions of this series in Cape Colony see Stow, *Q. J. G. S.*, xxx., 612; *G. C.*, iv., 78; x., 151, 249; xi., 22, 107; xii., 60, 144, 176. R. B. Young, *T. G. S. S. A.*, ix., 57.

and then south-west from Vryburg along the right flank of the Harts-Vaal Valley.

The Campbell Rand series consists mainly of blue dolomitic limestones. With the limestone there is frequently found grey or black chert in irregular layers parallel to the bedding of the limestone or in veins and along joint-like surfaces lying in various positions. There are also occasional quartzites, and frequently beds of shale, the latter being well represented near Schmidt's Drift. The limestones are the characteristic rocks of the group; they weather with a peculiarly channelled surface, which is also found on limestones of the Malmesbury and Cango beds of the south, and of the Dwyka series and many older rocks[1] in the north of the Colony. The weathered crust varies in co'our according to the amount of iron and manganese in the rock; where the iron or manganese is abundant, the surface has a deep reddish- or blackish-brown colour, otherwise the colour is greyish brown or grey. The country occupied by these limestones is often very rough, though it is at the same time very flat as a whole. The limestone is often dissolved away along joints, which are then represented by sharply defined depressions a few inches or a foot wide and several inches deep. The chert, also, adds to the roughness of the ground, for irregularly shaped masses of it project from the surface after the more soluble limestone has been removed.

In places the limestone is made up largely of oolitic

[1] The limestones of the Griqua Town, Black Reef, Wilgenhout Drift, Kraaipan and Kheis series are indistinguishable in hand specimens from those of the Campbell Rand group.

grains, small spherical bodies composed of concentric layers of carbonate of lime. The original structure of these grains has usually been destroyed by the recrystallisation of the carbonate, and occasionally by the replacement of the carbonate of lime by silica.[1]

The limestone is often ferruginous, and the iron compounds are not always distributed uniformly through the bed, but occur as hæmatite in more or less spherical masses, or they are spread through variously arranged bands of limestone, probably in the form of carbonate of iron. Neither in the limestone itself, nor in any of the shale bands which are particularly frequent in the lower part of the series, have any determinable fossils been found, though a shell, probably a brachiopod, has been found in the limestone near Schmidt's Drift. The thorough change in the minute structure of the limestone due to recrystallisation of the carbonates has probably destroyed most of the fossils. It is hardly to be doubted that the limestone is of marine origin.

The limestones in the Kaap Plateau are traversed by fissures, joints widened by the solvent action of water, and from some of these water issues in the form of strong springs. The spring from which Kuruman is famous comes from one of these fissures which can be followed more than 300 feet underground. Its plan[2] shows that it is due to the enlargement of joint cracks. No large caves, like those of Wonder Fontein near Pretoria in the same group of rocks, have been found in this formation in Cape Colony.

[1] See R. B. Young, *T. G. S. S. A.*, ix., 57; and *G. C.*, xi , 24.
[2] *G. C.*, xi., p. 26.

Near Vryburg the limestone near the base of the series contains fragments of lava like many of the Pniel lavas and those in the Black Reef series.

In a paper already referred to in a footnote, Prof. R. B. Young shows that the dolomitic limestones may be changed into rocks which have the appearance and composition of quartzites, but in addition to quartzites which have such an origin there are others which are certainly sandstones converted into quartzites by the usual process of the deposition of quartz in the interstices. These rocks, however, are not abundant in the Campbell Rand series.

Some of the chert interbedded with the limestone was probably formed during the deposition of the beds on the sea-floor, for it lies in thin bands parallel to the bedding of the rock; but a much larger part of the chert has been formed subsequently, as shown by its irregular distribution through the limestone beds and its filling joints. Thin sections through the bedded cherts have not revealed traces of radiolaria or other organisms. Such grey or black cherts are always abundant and well developed in the upper half of the series; this feature is characteristic of the formation not only in the Colony but in the Transvaal as well.

Towards the upper limit of the limestones of this group layers of ferruginous chert or jasper occur, similar in all respects to those which form the bulk of the succeeding Lower Griqua Town beds.

The chief area formed by the Campbell Rand series is called the Kaap Plateau and it lies between the Asbestos Mountains and the Harts-Vaal Rivers. It is made of a thick sheet of the limestones dipping westward at low angles under the Griqua Town beds of the Asbestos Mountains. The area of the Kaap Plateau is some 6,000 square miles, and it has a remarkably flat surface, though its height varies from about 4,000 to a little over 5,000 feet. It is a good example of a "peneplain," and its origin will be discussed later. The surface of the plateau becomes more and more sandy towards the north, and near the Mashowing Valley it is covered by a deep layer of sand, which persists over nearly the whole of the rest of the area occupied by this formation north of the Mashowing. The width of the limestone belt is only twenty miles near the Orange River, south of which it is to a great extent covered by Karroo beds, but northwards it gradually broadens till it reaches a width of some eighty miles near Vryburg, when it contracts rapidly to twenty-four miles along the Mashowing and maintains that width past Morokwen; north of that area it is buried beneath superficial deposits, but curves towards the east and may join up with the Dolomite formation of the Transvaal. This great band of limestone is the western limb of a broad and gentle anticline, the axis of which is occupied by the Vaal River, and the eastern limb lies in the Transvaal and under the Karroo beds in the Orange River Colony. The formation reappears to the west from under the Griqua Town beds in the Maremane anticline, of which the northern end is buried under sand; in the Wilgeboom anticline traversed by the Orange River below Prieska; on the south-west flank of the Griqua Town beds in Prieska and Hay; and at one place in the eastern hills of the Korannabergen. There is a great contrast between the condition of the beds on the two sides of the group of synclines occupied by the Griqua Town series stretching northwards from the Prieska district through Griqualand West into Bechuanaland. On the east side the beds lie at very low angles; in the middle anticlines they are rather more bent, and on the western side, where they are seen only at the southern end and for a short distance in the Korannaberg, they are much disturbed. In the Prieska area and in the neighbouring part of Hay on the south-west side of the Griqua Town belt they are entirely absent for several miles together, having been faulted out between the Black Reef, Ventersdorp series, or the granite on the south-west and the Griqua Town beds on the north-east.

The thickness of this limestone formation is difficult to estimate, but probably a value of between 2,000 and 3,000 feet will not be far from the truth.

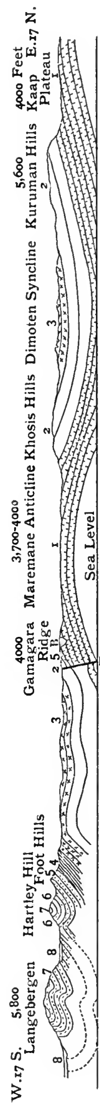


FIG. 7.—Section from the Kaap Plateau to the Langebergen, distance 66 miles; vertical to horizontal scales 3 to 1.

1. Campbell Rand series.
2. Lower Griqua Town beds.
3. Middle Griqua Town or Ongeluk beds.
4. Upper Griqua Town beds.
5. Lower Matsap beds.
6. Middle Matsap beds.
7. Upper Matsap beds.
8. Surface sand, etc. B, Blink Klip breccia. F, Paling fault.

C. The Griqua Town Series.

The village of Griqua Town stands at the foot of a long range of hills made of a very remarkable group of rocks the lowest members of the Griqua Town series.[1]

The series is divided into three groups:—

The Upper Griqua Town beds.
The Middle or Ongeluk beds, chiefly of volcanic origin.
The Lower Griqua Town beds.

Throughout their range in Cape Colony these beds appear to form a continuous succession, lying conformably on the Campbell Rand series, but there may be a slight unconformity between the two lower groups.

The Lower Griqua Town Beds.

The characteristic rocks are banded cherts or jaspers, coloured in various shades of yellow, brown and red by hydrated oxides of iron, black by magnetite or blue by the soda-amphibole called crocidolite; but there are also quartzites, sandstones, grits, shales, limestones and tillite or hardened boulder-clay of glacial origin. All the latter rocks form quite a subordinate part of the group, though some of them are of great interest.

The Lower Griqua Town beds are occasionally seen to follow the Campbell Rand series conformably, as at Klip Huis and at other places on the same small anti-

[1] After some early descriptions by Burchell and other travellers the first detailed account of these rocks is to be found in Stow, *Q. J. G. S.*, xxx., 581, later details in *G. C.*, iv., 80; x., 156; xi., 31; xii., 61, 176; and xiii. Also in *T. G. S. S. A.*, ix., 5; *Rep. S. A. A. A. S.* for 1906, 261.

cline below Prieska; where such sections are exposed banded magnetic jaspers are found interbedded with the upper layers of limestone in the Campbell Rand series, and show that the change of circumstances which caused such a striking difference in the nature of the sediments was not sudden and final, but was completed only after one or more recurrences of the formation of the limestones. The contrast in their ways of weathering is responsible for the fact that the passage beds are not often exposed. The Campbell Rand limestones are much more readily dissolved by water in the soil than the siliceous rocks of the Griqua Town beds, but they do not break up into small fragments like the latter, hence the slopes of the escarpments are covered by loose thin pieces of the jaspers, and the limestones are usually first seen in large slightly curved surfaces some distance below the junction of the two series.

The lowest beds of the Griqua Town group are often found to be sharply bent in various directions, while the limestones below lie flat or at a low angle, and the Griqua Town beds themselves at a varying distance from their base are also very little disturbed and dip conformably with the limestones.

These phenomena have been noticed at many places along the eastern escarpment of the Griqua Town series, but especially near Daniel's Kuil,[1] and in the area of the Maremane anticline. They have not been seen along the south-west border of the formation, nor round the small anticline below Prieska. The best exposures of highly contorted rock are to be found in outliers of the

[1] See *G. C.*, xi., 35.

Griqua Town beds on Mount Carmel, one of which was called Ramaje's Kop and described by Stow,[1] who thought the disturbances were due to earth-movements of the kind that produce mountains, but the thin belt of rock to which the contortions are confined and the geology of the neighbourhood give conclusive evidence against this view. In several places the bent strata are seen to lie in hollows in the limestone caused by the removal of a part of the latter; that this removal was not entirely due to denudation in early Griqua Town times is very probable, because the Griqua Town beds are lying in positions that are quite incompatible with the view that they were deposited in hollows thus formed, for the uniformly thin beds involved in the folds show no thickening towards the hollows below, but were evidently bent after their deposition on a level floor. There is no way of avoiding the conclusion that the hollows were produced by solution of the limestone, a rock that is much more easily dissolved than the overlying siliceous and ferruginous beds, and that the latter collapsed into the cavities thus formed. There seem to have been two stages in this process, one in which the Griqua Town beds filled the hollows without being broken but by bending readily, and a second in which they broke up, the fragments falling into the cavities, which were at the same time being filled with oxide of iron, chiefly hæmatite, derived from the overlying ferruginous strata. In addition to the iron oxide, silica forms part of the matrix in such cases. In Ramaje's Kop and the neighbouring outliers

[1] *Q. J. G. S.*, 1874, 665; see also *G. C.*, xi., 36.

the results of both these processes can be seen, but the formation of the highly ferruginous breccia is best developed in the Maremane anticline, a broad limestone area with numerous outliers of the Lower Griqua Town beds. The peculiar rock called the Blink Klip breccia from its occurrence at a place of that name near Postmasburg, where the abundance of small crystals of specular iron in the rock give it a glittering appearance, is the extreme stage reached.[1]

The breccia occurs in two long narrow ridges, the Klip Fontein and Gamagara hills, the latter over thirty miles long, and in many smaller outliers. At Wolhaar's Kop it is still in connection with higher beds in the series, elsewhere it is either uncovered, or, as at Gamagara, directly overlain by the Matsap beds. At Blink Klip itself, the breccia is seen to fill a wide fissure or cavity in the Campbell Rand beds, for the latter are exposed in contact with the breccia far above its base; but elsewhere the relations of the two rocks are not so obvious. In all the large masses of breccia, which may exceed 400 feet in thickness, the lower parts are made of smaller fragments and have more ferruginous matrix in proportion to rock fragments than the upper. In many cases a general increase in the size of the fragments upwards is noticeable, and many blocks of thinly banded rock are found on close inspection to have been shattered, but the innumerable fragments are but slightly displaced and are cemented together by a ferruginous and siliceous matrix.

[1] Details as to the occurrence of this rock will be found in *G. C.*, x., 174, and xi., 35.

The fragments are invariably angular, and they are, without exception, rocks of a type usually found near the base of the Griqua Town series. The only change they seem to have undergone is due to enrichment in iron oxides.

The hills made of the breccia are dark red, often almost black in colour, and have steep, rugged sides. One of the smaller hills, Kopje Alleen, is shown in Plate II.; it is rather less than 100 feet high and rises from the Campbell Rand limestone which is exposed on the surrounding flat ground.

Where the Blink Klip breccia is absent the banded and magnetic cherty rocks form the lower 2,000 feet or so of the series. They are for the most part thin bedded, the individual layers are rarely more than half an inch thick. Silica in the form of chert, seen under a high power of the microscope to consist of minute interlocking areas of quartz, forms the base of at least a great part of these rocks, but with the silica there occur red and yellow hydrated oxides of iron in minute particles and magnetite in rather large grains, often with octahedral faces. Traces of carbonates, either irregularly distributed in short layers or scattered through the rock in small rhombohedral crystals, in which the carbonate is often partly or wholly replaced by chert, are frequently seen. The magnetite is very much more abundant in some layers than in others, and these evidently represent originally richly ferruginous layers.

Perhaps the most remarkable feature in this singular group of rocks is the widespread occurrence in them of the soda-amphibole, crocidolite. Crocidolite is a blue

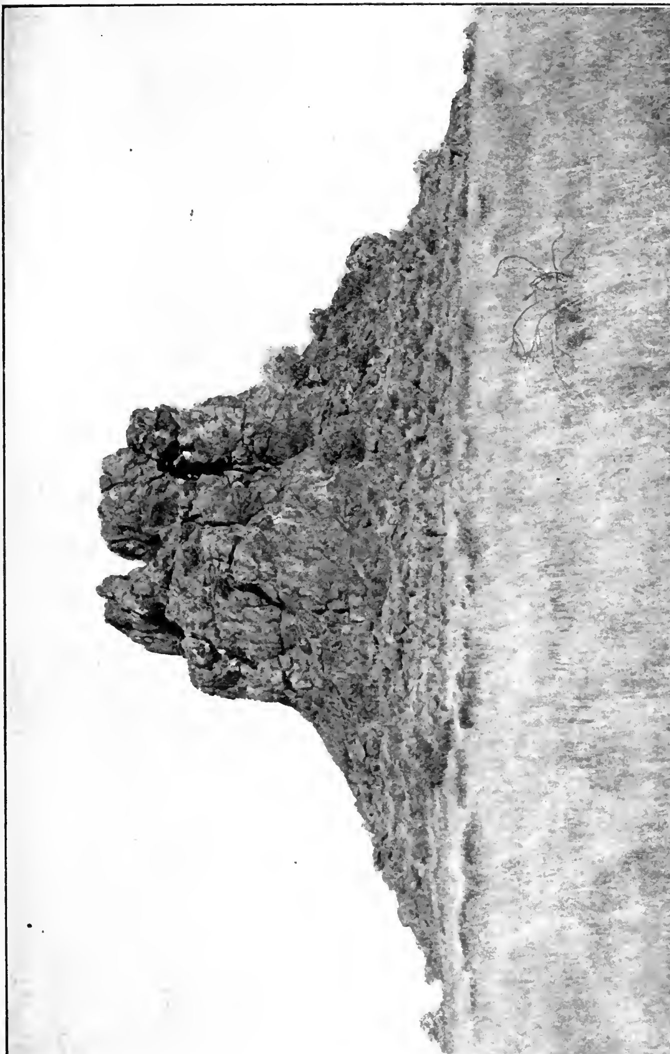


Plate II.—Kopje Alleen, near Mount Huxley, a hill made of the Blink Klip breccia rising from a plain of Campbell Rand limestone.

mineral which forms compact, heavy and exceedingly tough layers, and also fibrous layers, usually parallel to the enclosing siliceous beds. The compact rock consists of minute crystalline fibres of crocidolite matted together and not arranged in any uniform way; but in the fibrous rock each crocidolite individual has a length which may be more than 100 times longer than its width, and they are arranged parallel to one another and perpendicular or at a high angle to the surfaces of the enclosing rock. This fibrous form is flexible and is mined and sold under the name of blue asbestos. The two forms of the mineral are alike in their optical properties and composition.[1] There can be no doubt that the compact form is the result of the alteration in place of sediments deposited under water; it is found, just as any other variety of sedimentary rock, in layers between rocks, which differ from it in containing a smaller proportion of crocidolite grains or short fibres. The fibrous layers, on the other hand, may vary much in thickness within a very short distance, especially where the rocks happen to be bent. In these folds the fibrous crocidolite thickens out considerably in the arches and troughs, and when the enclosing rock is broken the cracks are often found to be filled with it. The fibrous variety thus behaves more like minerals filling veins than the compact sort, but it chiefly occurs in layers which maintain their width over at any rate many square yards, as proved by mining operations, and which lie conformably between two other beds without breaking across them.

[1] Analyses are quoted in *G. C.*, x., 158, from Hintze's *Mineralogie*, vol. ii., p. 1265, and other works.

Though the blue mineral was described under the name of crocidolite, and is so called in all the text-books of mineralogy, that term is commonly used in this country to denote the various altered forms due to the oxidation of the ferrous iron and the replacement of the greater part or even the whole of the iron and all the soda, magnesia and lime by silica. The extreme product is white fibrous quartz, but all the intermediate stages between this and the unaltered blue crocidolite can be found. The variously tinted brown and yellow mineral, which takes a high polish and which is made into ornaments on account of the beautiful shades of light reflected from its fibres, is in one of these stages of alteration. Crocidolite or its altered form is found in the Lower Griqua Town beds throughout their extent in the Colony, from Prieska in the south to beyond Heuning Vlei in the north. It seems to be more abundant in the lower half of the group than the upper, but it is not confined to the former. Even where it is not present in sufficient quantity to give the rock a characteristic appearance, it is often found in examining thin sections under the microscope.

Quartzites, sandstones and grits are occasionally found at various horizons, in the Lower Griqua Town beds, but there is no one band of such rocks which extends over a very wide area.

Limestones are occasionally found in the lower part of the group, but their chief position is near the top, usually about 100 or 200 feet below the Ongeluk lavas. In appearance they are like the more ferruginous varieties of the Campbell Rand limestone. They vary in thickness but have been found throughout the area occupied by the Lower Griqua Town beds.

Wherever the top of the Lower Griqua Town beds is exposed a peculiar boulder rock has been found lying within some thirty feet or less of the overlying Ongeluk lavas. It resembles a glacial till in having boulders and pebbles scattered through it at random, without any sort of arrangement according to size; the matrix is, where least altered, a fine-grained calcareous and siliceous rock with occasional grains large enough to be easily visible to the naked eye. The boulders and pebbles are often found to have one or more sides flattened and covered with scratches in the manner characteristic of stones found in tills. They are made of crystalline limestones and chert, and occasionally quartzites and grits, but such rocks as granites, schists and diabase have not been found as pebbles, though chips of felspar and flakes of mica, probably from granite, have been seen in thin sections of the matrix.

The general character of the rock and the shape of the striated boulders are extremely difficult to explain without assuming their glacial origin, even though a locality where the rock rests unconformably upon a striated surface has not been found. It is, in fact, a tillite, resembling in its chief features the tillites in the Table Mountain series and the Dwyka, the latter of which has been recognised by several geologists who have had wide experience of recent and Pleistocene tills to have been formed under the same kind of circumstances as these.

The source of the pebbles and boulders is not known;

the crystalline limestones are not like those of the Campbell Rand series nor are the cherts similar to those of the latter. A curious feature in the Griqua Town tillite is the occurrence of numerous nodules of chert unlike any that have yet been found *in situ* in South Africa. That these nodules are pebbles in the tillite and were not formed in it is proved by their having been scratched like other boulders and also by their manner of occurrence. The absence, so far as yet known, of boulders of granite, etc., is a very remarkable fact.

In its least altered state the rock has a blue or grey colour, but in many places it is red or brown owing to the presence of hydrated ferric oxides. Where the rock is red the limestone pebbles have been dissolved away, and their room is partly filled by specular iron ore.

The tillite is under 100 feet in thickness at the most, usually less. It is apparently thickest on the farm Punt in the Hay Division, but the rock is not frequently well exposed for measurement. Near Koegas it is only about ten feet thick. It has been found at many places between Madebing in Bechuanaland and the Orange River, and the area in which the known outcrops occur is some 8,000 square miles. It does not often make conspicuous outcrops, but where the Ongeluk beds form a prominent escarpment the tillite is often found at or near the base of it; otherwise the tillite is usually concealed by soil.

Above the tillite there may be a thickness of thirty feet of shales and jaspers between it and the lavas of the Ongeluk beds, but along the Kuruman River, near Upper Dikgathlon, the lavas follow the tillite directly, and the same may be the case on the farm Folmink near the Orange River.

The Lower Griqua Town beds form the longest range of hills in the north of the Colony. Starting from the Orange River near Prieska under the name of the Asbestos Hills it has a north-north-east course at first, but turns more and more to the north towards Daniel's Kuil and then to the north-north-west, where it is crossed by the Bechuanaland fence near the Gakarusa beacon; it maintains this trend past Kuruman (under the name of the Kuruman hills) to the poort of the Kuruman River, where it again turns north; beyond the place where it is cut through by the Mashowing it turns to the north-north-east again, and continues in that direction past Heuning Vlei. Though not an unbroken range, for it is crossed by the rivers named as well as by a tract of low ground near Daniel's Kuil, it is a distinct feature for some 300 miles, and even where the rocks are for miles together hidden under sand, as is the case north of the Mashowing, there is a belt of rising ground or "bult" to mark its position. It rises to its greatest height near the Bechuanaland fence, where the Gakarusa beacon stands 6,069 feet above sea level. Beyond Heuning Vlei the strike of the Lower Griqua Town beds turns more and more towards the east; but the rocks only appear in a few low hills projecting from the sand; they terminate at the Molopo near the north-western corner of the Mafeking Division.

This long sinuous course indicates the changes of strike of the Transvaal formation in Cape Colony more clearly than any other feature.

These hills present their steepest sides to the east, where their escarpment faces the Kaap Plateau. The rocks have a tendency to break away in vertical kranzes where deeply cut into by kloofs; elsewhere the outlines are remarkably smooth, though from the resistance of the rocks to the weather the surface is always covered with loose slabs of stone. It is only near the Orange River, where the gradients of the numerous stream beds, dry except during heavy rain, are steeper than usual that the forms assumed by the hills made of this group are rugged.

The Asbestos-Kuruman Range is the eastern edge of a group of synclines which become narrower and are formed by more steeply dipping beds towards the west and south. The positions of the larger synclines are marked by the outcrops of the Ongeluk beds.

The Doornbergen are a range of hills in Prieska made almost entirely of the Lower Griqua Town beds folded in a rather complicated way, and in part bounded on the south-west by thrust faults which in places bring the Pniel lavas, and even the granite, into contact with the Lower Griqua Town beds. The strike of the rocks is north-west, and the Orange River below Prieska cuts through them along the belt of country where the strike twists round from north-west to north-north-east.

The Middle Griqua Town or Ongeluk Beds.[1]

This group consists almost entirely of volcanic rocks, chiefly lavas of andesitic type, together with occasional

[1] Descriptions of these are to be found in *G. C.*, x., 179, 90; xi., 44-48; xii., 64-69; xiii.

layers of red and grey jasper and chert, and greenish flagstones.

The lowest lavas rest upon thin-bedded hard shales or upon the tillite of the Lower Griqua Town beds. The variation in the thickness of the shales, and their absence in places, perhaps indicate an unconformity, but so far as the general structure of the country is concerned the unconformity is of little importance. The Ongeluk beds have not been found lying directly on rocks older than the tillite. The lavas are as a rule easily distinguished from the others in the Colony by their appearance. They are fine-grained rocks with a devitrified matrix containing minute feathery microlites of augite, or hornblende, small felspars, and small crystals of enstatite or pseudomorphs after that mineral; the structure is of the kind called hyalopilitic. Amygdaloidal lavas, in which chalcedony, calcite and chlorite fill the steam-holes, are not infrequent. The Ongeluk lavas are less frequently amygdaloidal than those of the Pniel series. Volcanic breccias and tuffs are occasionally found.

Along the Mashowing and Kuruman Rivers some of the lava-flows have a peculiar kind of "pillow" structure, due to the presence of large blocks of lava which are separated from each other by a darker-coloured substance with a laminate parting parallel to the surface of the nearest block. The lava blocks may be as much as eight feet wide; they have rounded edges and corners, and the surfaces of adjoining blocks have complementary shapes.[1] The rock in the lava blocks is not amygda-

[1] Figures are given in *G. C.*, xii., 65, 66.

loidal, and is of the andesitic type usual in the Ongeluk group. The line between the blocks and the dark substance separating them is quite sharp. The dark matter is made of decomposition products such as chlorite, epidote and chalcedony, and in it are wedge-shaped masses of vein-quartz which fill up interstitial spaces due to decrease in bulk of the dark rock.

Peculiarly coloured jaspers or cherts accompany some of the lavas. They are brittle rocks, often with a very brilliant red colour, but some of them are greenish, black, or grey. The black cherts owe their colour to the presence of magnetite, the green to epidote, and the red to hydrous oxides of iron. Yellow garnets occur in these cherts in places. The red jasper is rather like some of the jaspers in the Lower Griqua Town beds, but it has a brighter colour.

The Ongeluk beds are well over 1,000 feet thick in Hay and Kuruman, but their thickness has not been closely estimated. It is difficult to measure their dip except in such escarpments as are formed by the lower part of the group.

In the Prieska Division they are found in a narrow syncline, both limbs of which dip westwards, on the farms Uitspansberg and Glenallan, and again farther south on Keikam's Poort. In Hay and Kuruman they occur in several broad shallow synclines, of which the largest is that of Witwater and Ongeluk west of Griqua Town. They have been found as far north as the Kgogole River near the road from Madebing to Heuning Vlei, but west of this region the superficial deposits effectually conceal the underlying rocks.

The Upper Griqua Town Beds.[1]

In the north-west part of Hay and the south-west of Kuruman there are sedimentary rocks lying above the Ongeluk lavas, and, as far as known, they follow the latter conformably. They are about 2,500 feet thick and are unconformably overlain by the Matsap beds of the Langberg. They consist of slaty rocks, phyllites, some quartzites, blue limestone, and red, black and brown magnetic cherts or jaspers, very like the thicker bedded jaspers of the Lower Griqua Town beds. They are to a large extent concealed by sand, which covers them entirely north of the farm Alister in Kuruman.

[1] escribed in *G. C.*, xi., 48-49.

CHAPTER V.

THE PRE-CAPE ROCKS OF THE NORTH (*CONTINUED*).

1. THE MATSAP SYSTEM.[1]

MATSAP in Hay is situated at the foot of a range of hills made of grits and quartzites. The same beds make a most conspicuous range of mountains in the north of the Colony, but it is broken up by stretches of flat ground and by the poorts of dry rivers. The southernmost part is the Ezel Rand of Prieska; the middle portion, called the Langebergen, consists of a main ridge separated from lower hills by tracts of sand; and the northernmost part is the Korannabergen, a group of mountains which gradually become lower northwards and finally disappear under the sand of the Kalahari.

Though not so long or so continuous as the ranges made of the Griqua Town beds these western mountains have much steeper sides, while the tops of the higher ridges have smooth outlines, like the Griqua Town ranges, in spite of the fact that the beds usually lie at high angles.

[1] These rocks are called the Langberg beds by Prof. Passarge in *Die Kalahari*, 1904, and *Süd Afrika*, 1907. They are probably the same group as the Waterberg system in the Transvaal, though a distinct connection between the two has not yet been traced. The earliest description is that of Stow, *Q. J. G. S.*, xxx. Fuller descriptions will be found in *G. C.*, iv., p. 82; x., p. 190; xi., p. 50; xii., p. 69; xiii., p. 89.

The series has been divided into three groups, but where the middle group is concealed or is absent there is always uncertainty as to the horizon of the strata. The divisions are:—

Upper Matsap beds, chiefly quartzites, grits and sandstones.

Middle Matsap beds, or Hartley Hill group, distinguished by the presence of volcanic rocks.

Lower Matsap beds, quartzites, shales and conglomerates.

The Hartley Hill group has only been found on the east side of the Langberg and is best exposed in the neighbourhood of Olifant's Hoek in the Kuruman Division.

The Lower Matsap Beds.

The base of the Matsap series is seen in the Ezel Rand of Prieska, along the eastern side of the eastern foothills of the Langberg, and in the Matsap and Gamagara ridges. Possibly also the western foot hills of the Langberg are made of the lower beds, and part of the Korannabergen, but these hills rise from the Kalahari sand which effectually conceals the rocks of the plain.

The chief features of the lower beds are the presence of conglomerates and shale bands in addition to quartzites and grits. In the Gamagara ridge the underlying rock is the Blink Klip breccia, and the basal conglomerate of the Matsap group is there crowded with fragments of the breccia and deeply coloured by hæmatite derived from it. A rather similar conglomerate crops out in the axis of a low anticline in the Matsap ridge, though the underlying rock is not exposed. At the south end of the ridge the Matsap beds are seen to rest unconformably upon the Griqua Town beds, but no specially thick conglomerate is found there.

In the high ridges of the eastern foothills of the Langebergen south of the Bechuanaland fence the conglomerates have a hard quartzitic matrix with pebbles of quartz, quartzite, jasper, diabase, and granite; they lie some distance above the base of the series. A superficial resemblance to the auriferous conglomerates of the Witwatersrand beds led to their being prospected for gold, but without success.

In the southernmost part of the Langebergen north of the Orange River, and in the Ezel Rand, really the continuation of the same range south of the river, there are conglomerates with a red ferruginous and quartzitic matrix with pebbles of quartzite, coloured jaspers, and occasionally diabase. In this part of the range the beds have been much sheared, and not only are certain beds repeated at the surface by faulting and folding, but the boulders and pebbles are stretched and flattened in a remarkable manner.

The shales are found chiefly in the eastern and western foothills of the Langebergen north of Pad Kloof, but they are also exposed in wells in the south of the Korannabergen. They are slaty rocks with a considerable amount of sericite.

The quartzites, sandy phyllites, and grits of the Lower beds are purplish- or reddish-grey rocks, but they have a bluish colour on recently exposed surfaces. They are usually rather coarse, and the grains are well rounded. There is no general difference between these quartzites and those which make up a large part of the middle and the whole of the upper group. Isolated well-rounded pebbles frequently occur in all these quartzites; they are made of quartz, quartzite, or red jasper; the latter often contains magnetite.

The quartzites of the Matsap group are different in appearance from other rocks in the Colony, and boulders of them in the Dwyka can be recognised with certainty.

The thickness of the Lower Matsap beds in Hay is estimated to be not less than 3,000 feet.

The Middle Matsap Beds.

The distinguishing character of these beds is the presence of a considerable thickness of volcanic rocks, lavas, breccias and tuffs. They have only been found east of the Langebergen between the farms Pauw Fontein in the south and Dalgetty in the north, a distance of sixty miles, while the length of the ranges from Ezel Rand to the north end of the Korannaberg is 140 miles. The volcanic rocks may exist over a very much wider area, for as the country is heavily covered with sand the rocks are usually only seen where there are hills.

At the base of the group near Olifant's Hoek there is a conglomerate with a dark green matrix like that of the overlying volcanic breccias. The lavas are much altered; they are often amygdaloidal and seem to have been of the hornblende-andesite type; original green hornblende and plagioclase are seen in some of the rocks under the microscope, but the greater part consists of green secondary minerals, cherty silica and calcite. The breccias and tuffs are dark green rocks with large and small fragments of lava in them. Round grains of quartz, felspar and jasper of considerable size, like the grains in the quartzitic grits, are usually seen in these rocks.

There are also conglomerates in this group, containing rounded boulders of lava as well as rocks older than the Lower Matsap beds. These conglomerates indicate local unconformities and the subærial waste of the lavas.

Together with the volcanic rocks and conglomerates the Middle Matsap beds include a great thickness of quartzites and grits, many of them just like the normal Matsap quartzites, but there are also white and green varieties.

The thickness of this group is not less than 4,000 feet, near Olifant's Hoek, the locality where they are best exposed.

The Upper Matsap Beds.

These rocks form the main range north and south of the valley cut through the Langberg by the Matsap River, and probably also the greater part of the Korannabergen (Plate III.). They consist almost entirely of purplish quartzites and grits, with a smaller thickness of gritty sericitic rocks, but there are no slates. Isolated pebbles of quartz and red jasper occur in these beds, but conglomerates seem to be absent.

The thickness of the Upper Matsap beds must be some thousands of feet, but as large folds are visible in various places in the Langebergen where transverse sections can be seen on the sides of kloofs the same beds are certainly repeated along any one section. On the west side there are nearly isoclinal folds with their axial planes inclined eastwards, but the general dip in the main range, as in the foothills on each side, is towards the west.

The Matsap series forms several ranges in the south-eastern corner of the Kalahari; the chief of them are the Inkruip, Karreeboom Laagte hills, the Kamkuip, the western hills of the Schuurberg, the Sagoup Range which is on the strike of the Korannaberg, and several small hills west of Sagoup. The rocks in these localities are like those of the Lower and Upper Matsap groups, but generally with a greater development of cleavage, owing to their containing more material favourable to the production of sericite, a characteristic mineral in rocks that contain clayey or felspathic material and have been subjected to great pressure during crustal movements.

A wide stretch of sand hides the rocks for a long distance north of the Korannabergen and the mountains in the Kalahari, but between Kolingkwane and Kuis on the Molopo steeply dipping purple quartzites which must belong to the Matsap beds crop out in the valley. They are unconformably overlain by the Dwyka series.

The mountains made of the Matsap rocks are very stony and have little soil on them. In this they resemble the ranges made of the Table Mountain sandstone of the south and west. There is, however, a great difference in the general appearance of the two groups of mountains due partly to lithological differences and partly to the contrast in climate of the two regions. The purplish

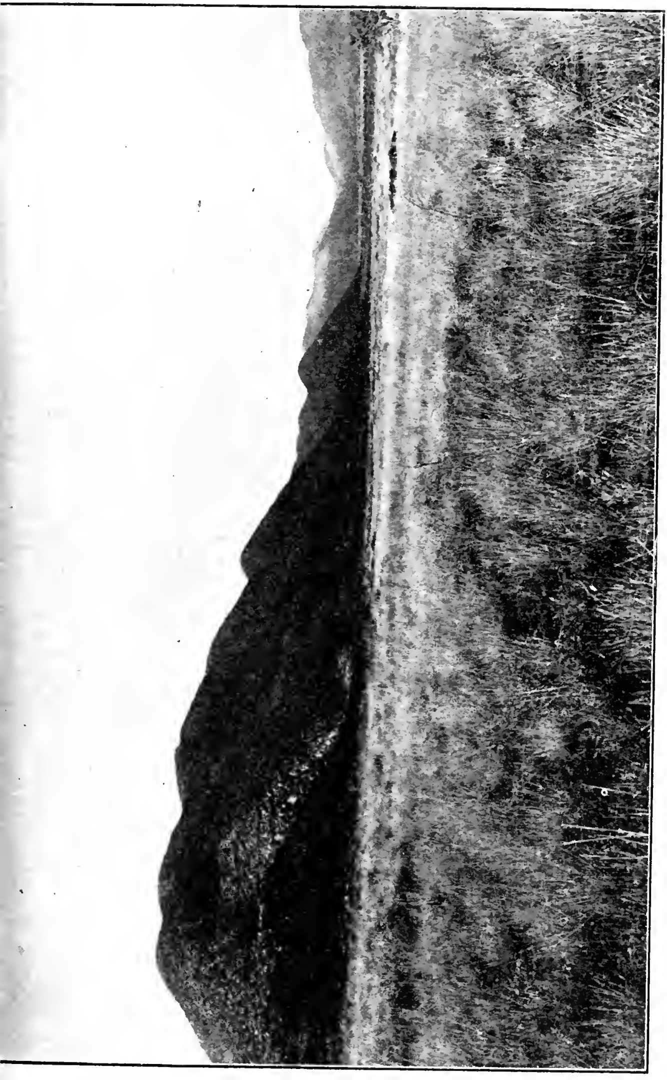


PLATE III.—The Korannabergen, north of Blaauw-Krantz, looking south-eastward. The beds dip westwards at about 40°, and are quartzitic grits of the Matsap series.

Matsap rocks do not give rise to white and black sandy soils like those of the southern ranges, but yellow or reddish soil lies between the stones. The Matsap beds weather into large and small rounded fragments, but they do not yield so unequally as the Table Mountain sandstones and quartzites, hence the strangely shaped crags and cliffs met with in the mountains made of the latter beds are not found in the northern ranges.

The Matsap series is supposed to belong to the Waterberg system of the Transvaal, but up to the present time the rocks in the two areas have not been connected by mapping. There is a general resemblance between the Matsap and Waterberg rocks, for they are both arenaceous formations, and both are intermediate in age between the Griqua Town (Pretoria) beds and the Dwyka.

The Matsap series has been correlated with the Table Mountain series; the reasons for that correlation are the arenaceous character of both groups, the fact that both are older than the Dwyka, and a desire to simplify the table of South African formations. The correlation is difficult to accept, in spite of its convenience, because the structure of the two areas is so different; in the south there is a conformable succession from the Cape into the Karroo system, and the farther north one follows the succession, *i.e.*, towards the country where mountain building of the southern period did not extend, the two formations become less and less disturbed while the Cape system gradually disappears owing to denudation in Dwyka and Pre-Dwyka times; in the north, on the contrary, although the Dwyka is as little disturbed as it is in Calvinia, where it lies on the nearly horizontal remnant of the Table Mountain series, it rests on the greatly folded Matsap beds which are in places 10,000 feet thick at least. Now this folding of the Matsap beds cannot have taken place at the surface; when they were being folded they must have been covered by some considerable thickness of rock since removed, and they themselves were denuded away over large areas in Pre-Dwyka and Dwyka times. If, then, the Matsap beds belong to the Cape system these 10,000 feet of rock in the north must have been deposited and then folded under the pressure of superincumbent strata, and a very great amount of denudation must have taken place, while the Cape system and the Dwyka, together less than 12,000 feet thick, were being deposited in the south. The improbability of this having been the case invalidates the correlation of the Matsap and the Table Mountain series, and justifies the placing of the former with the Pre-Cape formations.

2. The Zwart Modder Series.[1]

On the western side of Gordonia a group of sandstones, quartzites and shales is found lying nearly horizontally on the granite and unconformably covered by the Dwyka. These beds extend from Aries to beyond Rietfontein, a distance of about 100 miles, though covered over long stretches by the Dwyka, and they undoubtedly occupy a wide area in German South-West Africa; eastward they disappear under the sand of the Kalahari.

The basal shales and sandstones are usually reddish, but the highest beds seen are dark blue or grey micaceous

[1] *G. C.*, xii., p. 43.

shales. That they were formed under shallow water conditions is proved by the frequence of false-bedding, ripple marks, and clay pellets in the arenaceous rocks.

The only locality where the Zwart Modder beds have been found dipping at fairly high angles is the neighbourhood of Sannah's Poort, where an anticlinal fold trends south 35° west.

The exposed thickness of these beds is not less than 1,600 feet, and the total thickness probably exceeds that figure considerably.

At present the correlation of the Zwart Modder beds with other formations in the north or south is impossible. Resemblances to other arenaceous formations can of course be seen in them, but for all that is known they may with equal probability be assigned to any formation younger than the Malmesbury and Kheis beds and older than the Dwyka.

Miscellaneous Intrusions of the North.

In the Pre-Cape rocks of the north there are many igneous intrusions, chiefly dykes, which possess various petrological characters. Their exact age is uncertain, but that they are Pre-Karroo is indicated either by their petrological character or by the fact that they pass below and do not penetrate the Dwyka tillite.

In the southern part of Prieska Poort in the Doornberg the Griqua Town beds are penetrated by a small boss or plug of pink syenite. Syenitic dykes, probably of the same age as this intrusion, are found in the western hills of the Doornberg.

Near Klip Fontein in Hay there is a dyke of quartz-mica-augite-diorite. The felspars consist both of orthoclase and plagioclase; hornblende is more abundant than augite. This rock may perhaps be one of the later groups as it resembles in some respects the rocks of the Transkei-gap dykes.

A long dyke of diorite containing augite, hornblende, enstatite, biotite and plagioclase felspar cuts the granite area at T'Kuip near Omdraai's Vlei.

Diabases of various types are met with in all the formations from the Kheis to the Matsap series. In some varieties there is quartz often intergrown with felspar to form micropegmatite. The augite has usually been partially or wholly converted into pale green fibrous hornblende (uralite), but in some dykes there is an original green or brown hornblende; enstatite is not uncommon. These intrusions are usually fine or medium grained, but occasionally they may have porphyritic felspar crystals as much as an inch across. Several large intrusions of diabase in the Lower Griqua Town beds in Hay must, from their petrological character, be regarded either as sheets formed during the pouring out of the Middle Griqua Town (Ongeluk) lavas or as feeders by which these volcanic rocks reached the surface.

In the Prieska district there are several masses of gabbro and hornblende-pyroxene-picrites, the ages of which are unknown. One of the picrite dykes near Kheis has been taken to be a basic member of the Karroo dolerites, but this is doubtful. Another mass, with the character of olivine-gabbro at Brakbosch Poort, has been invaded by granite and grades into hornblende-schist. The picrites contain both augite and hypersthene.

CHAPTER VI.

THE CAPE SYSTEM.

THE rocks belonging to the Cape system have only been found in the southern part of South Africa; from Van Rhyn's Dorp in the west, round the coastal districts to the Gualana River, and again northwards from the St. John's River into Natal, the Cape system plays an important part in the structure of the country.

The true succession of these rocks was made out in part by A. G. Bain, but the numerous folds into which they have been thrown in the west together with some lithological resemblances between parts of the two upper series were responsible for the mistake he made in limiting the occurrence of the Witteberg series (the "Carboniferous" group of Bain) to the eastern province. Moreover, it is evident from the gap left in his map between the Kammanassie and Cockscomb Mountains that Bain never had the opportunity of connecting the west and east satisfactorily. This was partly accomplished by Wyley and Dunn; but meanwhile a serious error had been introduced by certain observers[1] taking the Bokkeveld beds to be lower in stratigraphical posi-

[1] Rubidge, *Q. J. G. S.*, xv., p. 195, etc. Hochstetter, "Beiträge z. Geol. d. Caplandes," in *Reise der Oesterreichischen Fregatte Novara um die Erde, Geol. Theil*, vol. ii., p. 31, 1866. Cohen, *N. J. für Min.*, etc., Beil., Bd. v., 1887, p. 202.

tion than the Table Mountain sandstone, a mistake that led to the identification of the Bokkeveld and Malmesbury beds on the one hand and of the Table Mountain and Witteberg series on the other. This unfortunate confusion which is not met with in the maps or writings of men who had a considerable personal knowledge of the rocks concerned, such as Bain, Wyley and Dunn, did much to obscure the interpretation of the structure of the Colony. The work of the Survey has clearly demonstrated the correctness of Bain's view of the superposition of the Bokkeveld on the Table Mountain series, and the extension of the Witteberg series over wide areas in the south-west, which were indeed made plain by Wyley[1] and Dunn.[2] The three members of the Cape system have now been so frequently traversed and mapped between the Cederbergen and Uitenhage by the geologists of the Geological Commission,[3] that there can no longer be any doubt as to their relationship to one another.

1. The Table Mountain Series.

This group of rocks forms the most conspicuous features in Cape Colony. Table Mountain itself, rising 3,553 feet above the sea, is visible long before the ship that brings the new-comer to South Africa reaches Table Bay, and on the mountain several characteristics

[1] Wyley, "Report of the Geological Surveyor," etc. Parliamentary Report, G, 54. Cape Town, 1859.

[2] Dunn, Geological Sketch Map, 1872, 1875, 1887.

[3] *G. C.*, i.-x. For a more detailed account of the history of the question, see Corstorphine, *G. C.*, ii., p. 31, etc. and *Rep. S. A. A. S.*, 1904, 148.

of the series can be seen. The Peninsula mountains, however, are merely outliers of the main portion of the Table Mountain beds in the Colony.

A description of the distribution of the series will serve also as a description of the main structural features of the southern part of the Colony. The broad outline of the structure has been given in the Introduction, but as nearly every important anticline in the south is marked on the surface by a ridge of Table Mountain sandstone, a more detailed account will not be out of place here. The position of the main anticlines mentioned below will be found in the map at the commencement of the volume.[1]

On the seaward side of the folded belt of sedimentary rocks forming the southern part of the Colony the Table Mountain sandstone becomes less steeply folded over large areas than anywhere within the belt itself. On the west, in the coastal plains of Clanwilliam and Piquetberg, the sandstone lies at low angles; by its removal the underlying Malmesbury beds and granite have been laid bare in the divisions of Van Rhyn's Dorp, Piquetberg, Malmesbury, Cape, Paarl and Stellenbosch, and the outliers of the Peninsula mountains, Riebeek's Kasteel and Simon's Berg, bear testimony to its former extension over that part of the south-west as a gently undulating layer.

A long outlier, bounded by a fault on the north-east

[1] Sheets 1, 2 and 4 of the Geol. Map of Cape Colony illustrate the south-western corner of the country. The rest of the folded belt has not yet been published in that series, but portions will be found in *G. C.*, viii., ix. and x.

side, forms Joostenberg in the south of the Malmesbury division; Klapmuts Hill, on the same line of strike, is a similar faulted outlier north-west of Simon's Berg.

To the east of the Peninsula the present coast line passes somewhat irregularly through the marginal part of the folded belt, for although the Table Mountain sandstone of the south coast is more folded than in the Peninsula of Piquetberg, yet the plications are fewer and much less abrupt than farther inland. The shore at Cape Hangklip, Hermanus, Danger Point and Agulhas, as well as at many intermediate points, is cut out of the slightly bent sandstones. East of Agulhas the coast trends to the north of east and cuts across the folded belt slantingwise, and the sandstones of Capes St. Blaize, St. Francis and Recife are highly inclined, for they lie well within the folded belt. There is no direct evidence of the nature of the rocks under the sea-floor, but it is probable that the Table Mountain sandstone is continued in a slightly bent condition some distance towards the edge of the Agulhas bank. The condition of the sandstone off the south-east coast is of course quite unknown, but from the close analogy between the structure of Pondoland and Natal, and that of Van Rhyn's Dorp, we may suppose that the Table Mountain series extends in a bent condition east of Port Elizabeth and that the strike turns round towards the north-east.

In the west the first (see Fig. 8) pronounced folds met with form the sandstone mountains on the left side of the Olifant's River Valley, where the sandstone is thrown into gentle anticlines trending north-north-west. The valley of the Olifant's River, from its source west of

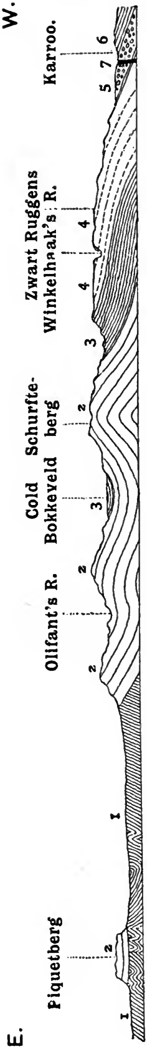


Fig. 8.—Section from Piquetberg to the Karroo. Distance about 68 miles. Vertical scale $\frac{1}{16}$ in. to 1,000 feet.

1. Malmesbury beds (the folding is diagrammatic).
2. Table Mountain series.
3. Bokkeveld series.
4. Witteberg series.
5. Dwyka series.
6. Ecca series.
7. Dolerite dyke near Hartnek's Kloof.

the village of Ceres to a point below Clanwilliam, occupies a syncline in which remnants of the Bokkeveld beds are still preserved at three places. South of Pikenier's Kloof the western limb of the anticline west of the river has mostly been removed by denudation, and the sandstones of the Olifant's River, Twenty-four Rivers and Roode Zand Mountains, and of the mountains still farther south along the same line, called the Drakensteins, and of those between French Hoek and Hangklip, form a long rugged escarpment, deeply embayed at French Hoek and Jonker's Hoek by the head-waters of the Berg and Eerste Rivers.

Northwards from Clanwilliam the Table Mountain sandstone is very slightly folded, but dips at a low angle eastwards, and its western edge is a fine escarpment, called the Nardouw Berg, Gift Berg, the Matsiekamma (Plate IV.), Kobe, and Bokkeveld Mountains in different parts as it is followed to the north (see Figs. 2 and 6). The escarpment is cut far back by the Troe-Troe River,

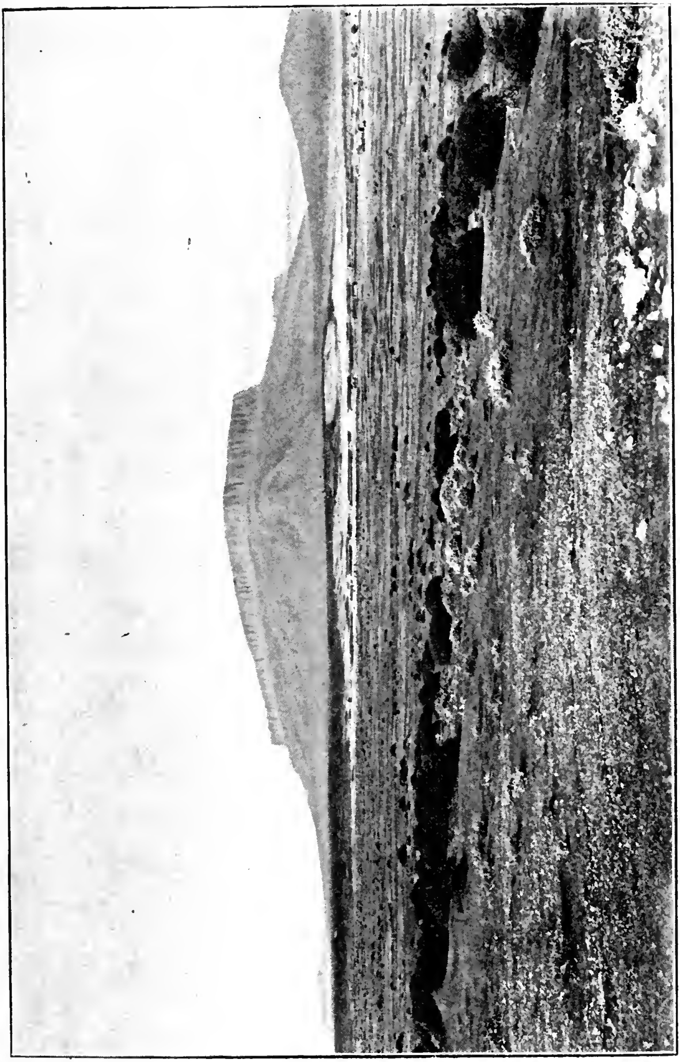


PLATE IV.—Matsiekamma from the N.W., a projecting portion of the Bokkeveld Mountain escarpment. The flat summit, with a kranz 600 feet high, and a further 400 feet of the slopes, are made of Table Mountain sandstone; the lower slopes are of Malmesbury beds.

and a part of Kobe Mountain is converted into an outlier by two sets of streams running on the one hand into the Olifant's River direct, and on the other into the Oorlog's Kloof River which lies in a deep precipitous valley behind the escarpment. The Table Mountain series comes to an end with the Bokkeveld Mountain, although the escarpment is continued some miles farther in the same line by the Ibiquas beds. The sandstone is only some three feet thick at its termination, but gradually increases in thickness southwards, so that at about thirty miles south of its northern limit possibly the whole 5,000 feet, the average thickness of the Table Mountain series, may be present. East of the Olifant's River lies the great anticline of the Cederbergen, which trends nearly northwest in its northern portion, but turns nearly north and south at the Trigonometrical Station (6,336 feet above the sea); in the same neighbourhood the syncline of the Cold Bokkeveld separates the main anticline from that of the Schurfteberg,[1] of which the axis diverges in a south-south-east direction and is inclined southwards, so that the anticline disappears near the Houd den Bek's River. The main Cederberg anticline is continued in the Cold Bokkeveld Mountains and the southern Schurftebergen. From the Schurftebergen the anticline passes round the warm Bokkeveld into the Hex River Range, closely backed by the Olifant's River syncline, so that the Table Mountain series in the block of

[1] There are two ranges called Schurftebergen (Rough Mountains) in that part of the Colony. The one here referred to is the more northern range; the other flanks the Warm Bokkeveld on the west and is the direct continuation of the Cederberg anticline.

mountains traversed by Mitchell's Pass is bent into an S-shaped fold. This fold becomes wider in the Hex River Mountains, the northern anticline forms the eastern part of that range, and the syncline is occupied by the Bokkeveld beds of the Hex River Valley. This S-shaped structure is repeated in the Keerom and Kwardouw Bergen, the anticline on the north forming the Wagenboom Berg and the syncline the Bokkeveld area of the Coo and the Keizie. The southern limb of the syncline, rather a closely folded belt than a simple limb, forms the commencement of the Langebergen to which we shall revert presently.

South of the Winterhoek (Tulbagh) mass, which is the southern limit of the western anticlines of the Olifant's River area, the valleys of the Klein Berg and Breede Rivers have been lowered through the Table Mountain series, and are now formed by the Pre-Cape rocks, separating the two great mountainous ridges of the Roode Zand-Drakenstein and the Witzenberg-Mostert's Hoek Ranges. The latter join with the southern Schurfteberg to form the Hex River Mountains described above. The former, which is affected by two groups of faults trending north-west and north-north-west respectively, is at first a simple ridge, but it gradually widens out, and south of Bain's Kloof it is broken by inliers of granite (Du Toit's Kloof), Malmesbury beds (Eland's Kloof) and of both granite and sedimentary rocks (French Hoek). It is folded along two directions; the north-east folds appear in the syncline of Bokkeveld beds on which Villiersdorp stands while the north-west folds bring the Table Mountain series down below the

Bokkeveld and Witteberg beds of the Breede River Valley south of Goudini.

The great block of mountainous country between Rawsonville and Cape Hangklip contains two irregularly shaped depressed areas, in which lie the Bokkeveld beds of the upper part of the Zonder Einde River, and those of the Houwhoek and Palmiet River district. The Groenland and Houwhoek Mountains have a north-west trend, and separate the two depressions. The country between Rawsonville and Cape Hangklip was, as it were, the hottest part of the battle-field where the north-south and east-west fold-producing forces met, and the resulting ridges and depressions trend north-west or north-east. The Boschveld, Groenland, and Houwhoek Mountains are the chief ridges of the north-west group, and the Zonder Einde and Houwhoek-Palmiet River Bokkeveld areas the corresponding depressions. The north-east group of ridges are the Dwars Berg-Bier River, and the Donkerhoek-Paarde Berg Ranges, while the corresponding synclines are those of the Villiersdorp and Bot River Valleys. The north-east folds extend eastwards as far as Lady Grey (Robertson) and as far north as the extremity of the Hex River Range.

The Zonder Einde Range, complicated by the north-east folds of the Lady Grey area, is an irregular anticline, and the beds in the northern limb dip down and come up against the Malmesbury beds along the great Worcester fault; to the south of the range the Zwartberg, better known as the Caledon Mountain, is the only conspicuous anticline that lies in the wide, synclinal area between it and the less disturbed Table Mountain sandstone ranges that stretch from Babylon's Tower to Bredasdorp.

The Worcester fault, with a maximum throw of more than 12,000 feet extends at least seventy miles towards the east, and plays the part of the southern limb of the complex anticline of the Langebergen. The Langebergen anticlines, although the mountains are known by other names, such as the Attaquas, Outiniquas, Long Kloof, Zitzikamma, and Kareedouws Mountains in their eastern portions, die out on the coast shelf of Humansdorp, 300 miles from their commencement at Hex River.[1] At many parts of the Langebergen the beds are overturned, so that the sandstones are overlain by older rocks on the south side, and underlain by newer beds on the north flank. The structure of the range is shown in the section accompanying the Geological Map and in Fig. 9.

To the north of the western part of the Langebergen the Table Mountain series disappears under the Bokkeveld and later beds of the country called the Ladismith or Small Karroo, a wide synclinal basin broken by the Warm Water Berg and Touw's Berg, east and west anticlines, which are rather steeply pitched at both ends, so that the shape of the Table Mountain sandstone areas is elliptical.

To the west of the Ladismith Karroo lies the Touw's Vlakte, with four small anticlinal ridges of sandstone, similar to Touw's Berg and Warm Water Berg except in size. The east end of the Ladismith Karroo is closed in by a series of three roughly parallel and pitching anti-

[1] Schwarz, *G. C.*, x., p. 74.

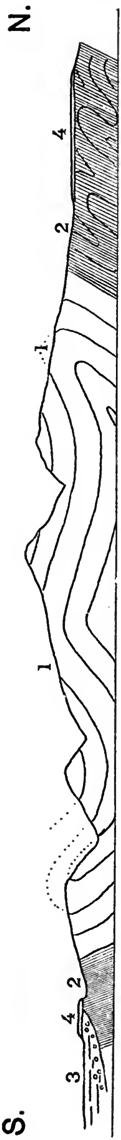


Fig. 9.—Section through the Langebergen in the neighbourhood of Oudebosch beacon showing the nature of the folding. Distance 11 miles. Horizontal and vertical scales the same.

1. Table Mountain series. 2. Bokkeveld series. 3. Uitenhage series. 4. Surface quartzites and gravels.

clines of Table Mountain sandstone, forming the Paarde Berg, Roode Berg and the Pogha Hills, which together make an irregularly shaped connecting ridge between the Zwartebergen and Langebergen, although the connection with the former range is incomplete owing to the presence of the Amalienstein fault.

The Zwartebergen commence in Anysberg (highest point, 5,322 feet), which is a westerly pitching anticline of regular form on the north of the Ladismith Karroo. The sandstones which pass under that country reappear in Anysberg, and are continued in the Zwartberg Range 160 miles before they sink below the Bokkeveld beds near the Zuurberg Poort. About twenty miles west of Ladismith village, the Amalienstein fault is first met with, throwing down the Bokkeveld beds on the south against the Table Mountain series; the throw increases eastwards, so that near Amalienstein the Bokkeveld beds are in contact with the Cango series. This fault is in many respects like the Worcester fault, and replaces the southern limb of the Zwartberg anticline for a considerable distance—over sixty miles.

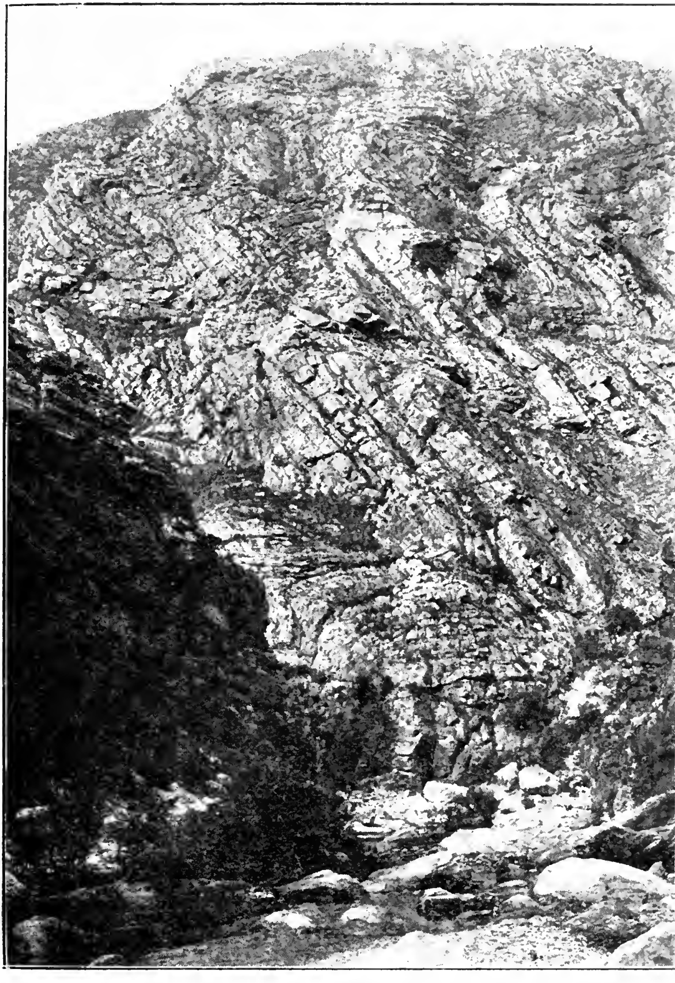


Plate V.—Contorted and overfolded quartzites of the Table Mountain series. A cliff about 400 feet high in Meiring's Poort (Zwartebergen), seen from the west.

The Zwartberg anticline has at least as complex a structure as that of the Langebergen, and is also overfolded in many places (see Plate V.), especially between Prince Albert and Klaarstroom; the overfolding affects both the north and south flanks. On the north the later rocks, from the Bokkeveld to the Dwyka, dip south towards the mountains near Prince Albert (see Fig. 4), and, as was described in the account of the Cango series, the Table Mountain sandstone dips in places below the latter. Where the Gamka River traverses the mountains there is a synclinal fold bringing in the Bokkeveld beds in the middle of the range, thus dividing it into two distinct anticlinal ridges for some ten miles. The highest point on the range is the peak near Seven Weeks Poort, 7,627 feet; the curious tower-shaped peak called Tover Kop is some 400 feet lower. Near Klaarstroom the Zwartebergen decrease considerably in width on account of the northern portion of the range separating from the southern and plunging below the Bokkeveld beds.

Between the Zwartebergen and the Outiniquas lies the great ridge called the Kammanassie Mountain, a bow-shaped anticline of sandstone with the concavity towards the north; the east and west ends of the axis pitch in those directions. Between the Kammanassie and the Outiniquas there is a much-folded ridge of sandstone that diverges from the main range near the Montagu Pass, and extends eastwards to form the Kouga Mountains.

The Table Mountain and Bokkeveld series, of which the country between Willowmore and Knysna chiefly

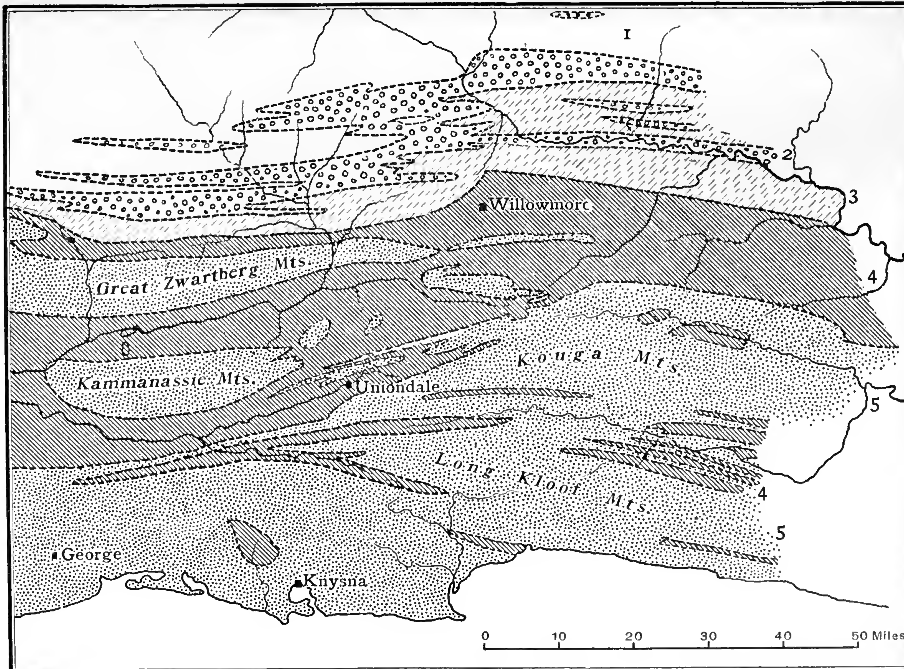


Fig. 10.—Map of the Folded Region.

1. Ecca series.
2. Dwyka series.
3. Witteberg series.
4. Bokkeveld series.
5. Table Mountain series (including some areas of Pre-Cape rocks).

The outliers of Uitenhage beds have been omitted.

Drawn from maps by E. H. L. Schwarz.

consists, have been intensely folded in this region and as far east as the neighbourhood of Algoa Bay, where they disappear under the sea. The trend of the mountains is east-south-east, and the chief ridges are the Baviaan's Kloof, Koega and Zitzikamma Mountains west of the Gamtoos River, and the Winterhoek and Eland's Berg Ranges east of that river. The chief feature of this area is the marked development of high level plateaux or terraces, from which the mountain ridges project, and in which the deep strike valleys of Baviaan's Kloof and Koega Rivers have been cut. The narrow synclinal or isoclinal troughs of Bokkeveld beds have usually been selected by the rivers, though the wide terraces high above them are cut indifferently through soft and hard strata alike.[1]

Beyond Cape Recife and St. Croix Island the Table Mountain series again appears east of the gates of the St. John's River in Pondoland. This river, just before it enters the sea, passes through a great block of Table Mountain sandstone, flanked on the north by Dwyka and on the south by Ecca beds, from both of which it is separated by faults.

The St. John's sandstone lies horizontally. A few miles north-east of St. John's the Table Mountain sandstone is again met with lying horizontally, overlain to the north-west by the Dwyka tillite, and on the south-east bounded by the ocean or separated by a

[1] Descriptions of the country by Schwarz are in *G. C.*, ix., p. 47; and x., p. 47; *T. S. A. P. S.*, xv., p. 43; *Amer. Journ. Sci.* xxiv., p. 185; and in Papers, etc., read at the joint meeting of the B. and S. A. A. A. S., 1905, p. 56.

fault from a narrow strip of younger rocks (Ecca and Cretaceous) between it and the sea (Fig. 3). The difference in level between the sandstone on the coast and that forming the plateau behind the coast is due to the cutting back of the lower terrace by the sea at no very remote period, and certainly not to folds or faults bringing the sandstone down near the coast.

The Table Mountain series is remarkably constant in lithological characters throughout its extent. The maximum thickness is about 5,000 feet, and of this more than 4,000 feet are sandstones or quartzites, often false-bedded. The difference between a sandstone and a quartzite is that the component grains are more loosely held together in the former than in the latter, in which the cementing material is quartz. When a sandstone is broken, the fresh face is rough and dull, owing to the fracture passing round or between the grains of sand which form the rock; a quartzite, on the other hand, has a smoother and brighter face because the fracture passes through the component grains, which are closely joined together by the siliceous cement. It is sometimes found that a large block of sandstone long exposed to the weather becomes a quartzite near the outer surface, owing to the deposition of silica between the grains. On the other hand, some quartzites become loose and crumbly outside on account of the removal of the cement.

The whitish-grey colour of so much of the sandstone belonging to this series is due to weathering. At a distance of one or two feet from the outside the rock is usually blue, owing to a small quantity of iron in the state of ferrous compounds. The reddish-brown layer so often seen on the broken surface of a large block of sandstone is produced by the oxidation of the ferrous compounds and the formation of a brown hydrated sesquioxide. This is slowly removed from the outer surface, so that a narrow band of light grey or white rock lies between the brown band and the exterior. The red stains so often seen on the sandstones are deposits of this red oxide of iron.

The sandstone has generally a very rough surface, frequently hollowed out so that it is covered with small and large projections, between which are shallow depressions that hold water for some time after rain. Particles of sand collect in these and give the depression a smoother surface than it otherwise would have had, by being moved about in it by strong winds. The gradual lateral growth of the hollows on steeply inclined surfaces of sandstone may eventually give rise to a perforation, or small arch, by meeting a joint plane or a second depression formed on another surface of the rock.

The sandstone is very much jointed; and as the processes of weathering naturally go on more easily along joint planes than elsewhere, for the loosened grains are soon removed by the rain or wind, the large exposed surfaces of sandstone are usually divided up by two or more sets of deep cracks, to which another group is added if the beds are so steeply inclined that the bedding planes make a high angle with the ground. Where these cracks become deeply eroded and are set at close intervals the ground is extraordinarily rough and difficult to traverse. The moderate effects of weathering along joints are familiar to every one who has been to the top of Table Mountain, where there are many curiously shaped knobs and pinnacles due to this cause combined with the unequal weathering of the surface. On the eastern slope of the Cederbergen, below Sneeuw Kop, on which a beacon of the geodetic survey stands, the surface of the hill is extremely cut up by these eroded joints. There are two main sets of joints on that slope, roughly parallel and at right angles to the strike of the beds, and a third group is sometimes developed. Weathering and erosion have gone on to such an extent that the mountain side is covered with an intricate mass of vertical walls and pinnacles of rock from five to forty feet high. Although such a fine development of joint weathering is not often met with, similar features are common on all the folded mountains made of the Table Mountain beds.

A very frequent feature in the sandstones of this group is the occurrence of rounded pebbles of white quartz up to three inches in length, though they are rarely more than an inch long. They are usually sparsely scattered through the rock, rarely in thin layers a few feet long. Conglomerates are of restricted occurrence, but they are found at Pikenier's Kloof, Baboon Point and a few other localities in the west, and in the Knysna and Uniondale Districts. Most of the pebbles are of quartz and quartzite. Granites and quartz porphyries have been found in the small outliers of Klapmuts Hill and Joostenberg, as well as at Baboon Point.

At the last-mentioned locality and in its vicinity pebbles of red jasper are abundant.

In the Peninsula and Stellenbosch areas the base of the Table Mountain series is usually a red micaceous gritty shale. On the north face of Table Mountain this is often the first rock met with at the junction with the granite or Malmesbury beds, though a thin layer of arkose is found in places directly overlying the granite. In many parts of the Langebergen there is a thick band of shaly beds near the base of the series, but the lowest beds are usually quartzites (see Plate I.). On the Montagu Pass the shales near the bottom of the series are exposed in the road cutting, and are found to be a crumpled silky phyllite or schist, in which the silky appearance is due to the development of minute flakes of a micaceous mineral.

A second shale band is found about 1,000 feet below the top of the series. The shales are usually hidden by *débris* from the sandstone cliffs above them, and it is only on road cuttings and tracks across its outcrop that the rocks forming the shale band can be well seen. The shales are exposed on the Mitchell's Pass road, where they are deeply weathered into a red micaceous sandy clay.

In the French Hoek Mountains there are black slates with pebbles on about the same horizon. In the Willowmore and Uniondale country there is a difficulty in distinguishing between these upper shales and the Bokkeveld beds, owing to their lithological similarity and to the fact that the Lower Bokkeveld beds have been folded in amongst the Table Mountain series forming long and narrow strips of slate in which the characteristic fossils are not easily found.

In the Cederbergen east of Clanwilliam the shale band is about 300 feet thick, but some 100 feet of rock at the base of the band consist of greenish blue or reddish mudstone without lamination, containing scattered pebbles and boulders, which show flattened and striated surfaces like those of glaciated boulders.[1] The boulders are made of quartz, quartzites, sandstones, red jaspers, amygdaloidal diabase and granite. The random distribution of small and large pebbles through a fine-grained matrix, together with their scratched surfaces, are evidence that the rock is a tillite, or hardened till or boulder clay, of glacial origin. In many respects it resembles the Dwyka tillite seen in the Karroo a few miles to the east of the Cederbergen. The best localities for seeing the outcrops of the Clanwilliam tillite are the road over Pakhuis Pass, the slopes of the mountains on Klein Vlei and Lange Kloof, and Bosch Kloof on the south-west or downthrow side of the Augsburg fault, which a little farther north causes the Bokkeveld beds to lie against the sandstone of the Table Mountain series below the shale band. The length of the lines along which these glacial beds have been followed near Clanwilliam is twenty-three miles.

The base of the glacial beds is exposed on the farm Bosch Kloof, where there is a gradual passage from the usual coarse quartzitic sandstones with scattered white

[1] For detailed descriptions see *G. C.*, v., p. 79; *T. S. A. P. S.*, xi., p. 236, 1902; *ibid.*, xvi., p. 1, 1905; and Schwarz, *The Journal of Geology*, xiv., p. 686, 1906.

pebbles into the greenish blue tillite. The glacial beds pass upwards into shale without pebbles by decrease in the number of pebbles and at the same time the appearance of lamination planes.

Recently a number of typically scratched pebbles and boulders[1] have been found on the "table" of Table Mountain itself, on a horizon 2,250 feet above the base of the series. The bed containing these boulders and pebbles lies at the base of the Kopje on which Maclear's beacon stands, and the pebbles and boulders are mostly found weathered out from the matrix and scattered over the plain from which the Kopje rises. Many of them are an inch or so in length, and are made of white quartz and quartzite; they had been well water-worn before they were striated. Fewer are of much larger size, varying up to a foot in length, and these show the characteristic shapes and scratches extremely well. Some of those boulders were found still embedded in the matrix, a gritty quartzite very unlike the dark-coloured mudstone of Clanwilliam. Though white quartz and quartzite are the most frequent materials, dark-coloured cherts, granite, and reddish coarse gritty quartzite, very like many of the Matsap quartzites, were found in this locality.

A very interesting quartz pebble is amongst those collected on Table Mountain; it has the character of sand-cut pebbles from desert regions, rather sharp but not quite straight edges separating nearly flat but slightly undulating faces; it is in shape a typical "driekanter".

The only traces of fossils yet found in the Table

[1] First found by Dr. R. Broom in Nov., 1908, and a few days later the writers found many other examples.

Mountain series are lamellibranch shells, not well-enough preserved for determination, which occur in thin-bedded and micaceous sandy shales at the very base of the series on the pipe track to the Slangoolie ravine above Camp's Bay.

The question of the conditions under which the Table Mountain series was deposited has not yet been satisfactorily solved. The rocks are, with the exception of the shale bands, essentially coarse-grained deposits, yet this character is maintained over very wide areas; from the Peninsula to Algoa Bay, nearly 430 miles in a straight line, and from Cape Point to the north end of the Bokkeveld Mountain, a distance of over 225 miles, the same coarse sandstone with isolated quartz pebbles is met with ; in Pondoland again, 290 miles from Algoa Bay, the sandstone is of identical character with that of the western area, and maintains its character at least as far as the Natal border. North of Agulhas the Table Mountain sandstone is seen at intervals for about 100 miles. It is clear, then, that the coarse sandstones that make up the bulk of the series were deposited over an area of at least 43,000 square miles, probably over more than 90,000 square miles, and even then the Pondoland outcrops have been left out of account owing to the uncertainty of the nature of the rock between them and Algoa Bay.

During the denudation of the land that furnished this great bulk of sand, mostly quartz sand, an equal or greater amount of finer-grained material, muddy matter, must have been produced, but of these fine-grained sediments the only traces in Cape Colony are the shale bands interbedded with the sandstones. The shales belong to definite horizons, or, in other words, were deposited during a certain part of the period instead of coarse sand like that which lies above and below them, but within the area of observation the coarse deposits do not pass laterally into the fine-grained ones. In any wide area of deposition such as that with which we are dealing, it is usual to find a considerable change in the nature of the material deposited, except in the case of oceanic deposits, the organic oozes and red clays which are formed far from land and under circumstances that vary but slightly over immense regions. The sandstones with which we are dealing, however, must have been formed near land, possibly to some extent on the land.

The great scarcity of fossils throughout the series is a very significant fact and, together with the character of the rocks, makes it impossible to regard the latter as of marine origin. Lacustrine conditions, for at least the greater part of the sediments, are also out of the question, because it is difficult to conceive of such a continuous accumulation of coarse sand in a lake. The nature of the rocks is such as to justify a comparison with the deposits found to-day in desert regions, but there are important points of dissimilarity. A frequent occurrence in deserts is the interbedding of soluble materials such as limestone, gypsum and salt with the sand and mud swept down from the hills by wind and rain. Their presence indicates either that the region had no outlet for its drainage, or that the slope towards the outlet was so slight that the scanty rainfall did not suffice to carry away the soluble material, which was therefore left at or near the surface on evaporation of the water. Hitherto such deposits, calcareous tufa, gypsum and salt, have not been observed in the Table Mountain series, nor have the rocks red and yellow colours, due to complete oxidation of the iron compounds and characteristic of desert sands. Perhaps the most likely explanation of the deposits is that they were formed by rivers flowing over a sinking area and carrying the fine-grained silt and the soluble matter beyond the area in which the rocks are now exposed to view. The thin layers of pebbles, the isolated pebbles scattered through a sandstone matrix, the frequent false-bedding, and the predominance of sandstone are in agreement with this view. The thick band of shale about 1,000 feet from the top of the series probably indicates the formation of a wide lake by subsidence, and in this lake glaciated stones were dropped by floating ice. So far as we know at present there are no traces of a rock or gravel floor over which solid ice moved, but glacial conditions prevailed over some part of the land surrounding the area of deposition. The strata above the shale band are sandstones precisely like those below it, and were doubtless formed under similar conditions.

The Table Mountain series yields a poor, sandy soil, which in spots continually kept damp is black, owing to the presence of organic matter. Vegetation is abundant where the rainfall is heavy; a heavier rainfall is recorded on or near the mountains of the south and west than on the low ground on the coast side or on the inland flank. The most characteristic plants seen on this formation belong to the orders *Proteaceæ*, *Ericaceæ* and *Restiaceæ*, respectively the sugar-bush tribe, heaths and flowering rushes. The change in the character of the vegetation on passing from the Table Mountain series to another formation is usually very sharply defined. From the Bokkeveld Mountains right round the great sandstone mountains of the folded belt, the same or similar shrubs and flowers are found. A most striking contrast to any one who is even slightly acquainted with the vegetation of the western mountains is seen on passing from the Karroo formation in Pondoland to the strip of country near the coast formed by the Table Mountain sandstone; leaving the monotonous grass veld of the interior of Pondoland one meets with the same flowers and small shrubs that are abundantly found on the western mountains. It is difficult to understand how such a distant outlier can be clothed with the same vegetation as the main area by a process of colonisation and selection by the soil; probably the plants of the Pondoland coastal plateau arrived there when the sandstone was still connected with the western ranges by the more or less rectangular strip, corresponding to the bent ranges round the Warm Bokkeveld, that may still exist off the south-east coast between the Gualana and St. John's Rivers.

Owing to difficulty of access by road and the general poverty of the soil, there are few farms under cultivation on the sandstone areas. The mountain veld is mostly used for grazing. Very rarely one finds a farm, such as Mouton's Valley on Piquetberg, where many kinds of fruit are grown, wine and tobacco made, and fine plantations of oaks laid out on the ground that was no better originally than that on hundreds of other mountain farms which are merely grazing veld.

From the old accounts of the Colony it is clear that the lower slopes of the southern mountains were once fairly well covered with forest, now represented by a few isolated patches, as at Groot Vader's Bosch near Swellendam. In the neighbourhood of the Peninsula and Stellenbosch, the oldest settlements in the Colony, the too free cutting down of the timber has been the cause of the almost complete disappearance of the indigenous forest, but farther north and east the chief cause of destruction has been the veld fires lighted for the purpose of allowing young grass and bush to spring up afresh for cattle to graze upon. There can be no doubt that the hindrance of the forest growth is a great evil, except perhaps to the farmers whose cattle graze on some of the mountains. There is a well-supported belief that forest-clad hills receive a heavier rainfall than the same hills deprived of their trees; but the destruction of forest and bush has a much wider effect than this. Living vegetation and the accumulation of dead twigs and leaves hinder the rapid dispersal of rain-water and bind the sandy soil, thus causing a more gradual delivery of the water into the streams, and at the same time allowing a greater proportion of it to sink into the ground than is the case in a deforested region. The rivers fed by the mountain streams, therefore, rise less suddenly and maintain their supply of water for a longer period; and the springs which get their water from the mountains are stronger and more constant.

The Knysna forest is chiefly on Table Mountain sandstone, and far to the north-east the St. John's and Egossa forests are on the same formation. Elsewhere the forests are mere remnants preserved in steep kloofs, and they do not spread over large parts of the mountain sides.

2. The Bokkeveld Series.

The Bokkeveld series is everywhere found lying directly upon the Table Mountain series, with similar strike and dip, and there are no signs of unconformity between the two. In some localities, such as the small sandstone anticlines in the Warm Bokkeveld and the anticlinal ridge of Jan Niemand's Bosch near Houwhoek, water seems to have percolated freely at the junction of the two formations, the position of which is marked by a layer of crystalline quartz. There are few places where a clean-cut section of the junction can be seen, for the soft beds of the bottom of the Bokkeveld group have generally been worn away by small streams, the beds of which are choked up by *débris* from the sandstones when the strata are at all steeply inclined. Where the beds lie nearly flat, as they do north of the Doorn River in the Western Karroo, the junction is hidden under the soil. The best section hitherto found is that on the left bank of the Gamka River immediately above its great Poort through the Zwartebergen, and there "the end of the white sandstones and the beginning of the blue-black shales of the Bokkeveld is so sudden and exact that one can place a knife between them and say confidently that on one side are the rocks of the Table Mountain series and on the other those of the Bokkeveld ".[1] Other clean-cut sections through the junction may be seen lower down the Gamka (Gouritz) River in the Pogha Hills and near the new road to Cloete's Pass, and at the north end of Meiring's Poort.

The Bokkeveld beds are well exposed in the Cold and Warm Bokkevelds, in the Hex River Valley especially between De Doorns and Klein Straat stations, and along the northern flank of the Zwartebergen. They occupy wide areas in the Ladismith Karroo and south of the Langebergen; but south of the Zwartebergen they have been greatly changed by the movements which gave rise to those mountains, and are much cleaved. They have only been found within the folded belt south and west of the Karroo. No outliers have been met with in the Pre-Cape region of the west and north, and in Pondoland they have been removed by denudation, if they were ever deposited there. There can be little doubt that they once overlay the sandstone of Table Mountain, although the nearest outcrop is at Grabouw, east of Hottentot's Holland, about thirty-six miles in a straight line from Table Mountain.

Where typically developed the Bokkeveld beds consist of shales and sandstone arranged in a definite order, although the details vary from one locality to another. The lowest division consists of shales and thin sandstones about 300 feet thick and contains many fossils, amongst which are trilobites belonging to the genera *Phacops* and *Homalonotus;* brachiopods of the genera *Leptocœlia*, *Spirifer*, *Chonetes* and *Orthothetes; Orthoceras,*

[1] Schwarz, *G. C.*, iii., p. 36. A detailed measured action through the Bokkeveld beds will be found in that Report.

Bellerophon, *Nuculites* and crinoids. The shales often contain spherical or elliptical nodules, which are partly filled with red or yellow ochre, sometimes used for making paints with the addition of oil. Another variety of nodule found in the shales is dark coloured inside, and often contains rather well-preserved fossils.

Some beds of the lowest shale group are coloured black by the amount of carbonaceous matter in them, and in places where the rocks have been intensely crushed these beds are represented by graphitic slate or schist, as on the north of the Pot Berg anticline near Port Beaufort and near Bredasdorp.

This subdivision usually forms a slope below a cliff or very steep rocky ground formed by the second division, the first or fossiliferous sandstone. The fossiliferous sandstone is a dark-blue rock weathering deep red outside; at some places the sandstone contains many fossils, especially *Spirifer* and *Leptocœlia*, but at other localities the sandstone is not nearly so fossiliferous. The beds of red-weathering sandstone are separated by blue shales very like those below and above this subdivision. The thickness of the fossiliferous sandstone reaches 150 feet. This rock can be seen north of the village of Ceres especially on the road up the Gydo Pass, where many fossils have been obtained from it. It is very often seen as an escarpment, the steep face of which is directed towards the Table Mountain sandstone. Such an escarpment occurs for a long distance, over fifty miles, on the east side of the Cederbergen, where, owing to the steep but constant dip of the beds south of Wupperthal, the whole of the Bokkeveld series is exposed within a

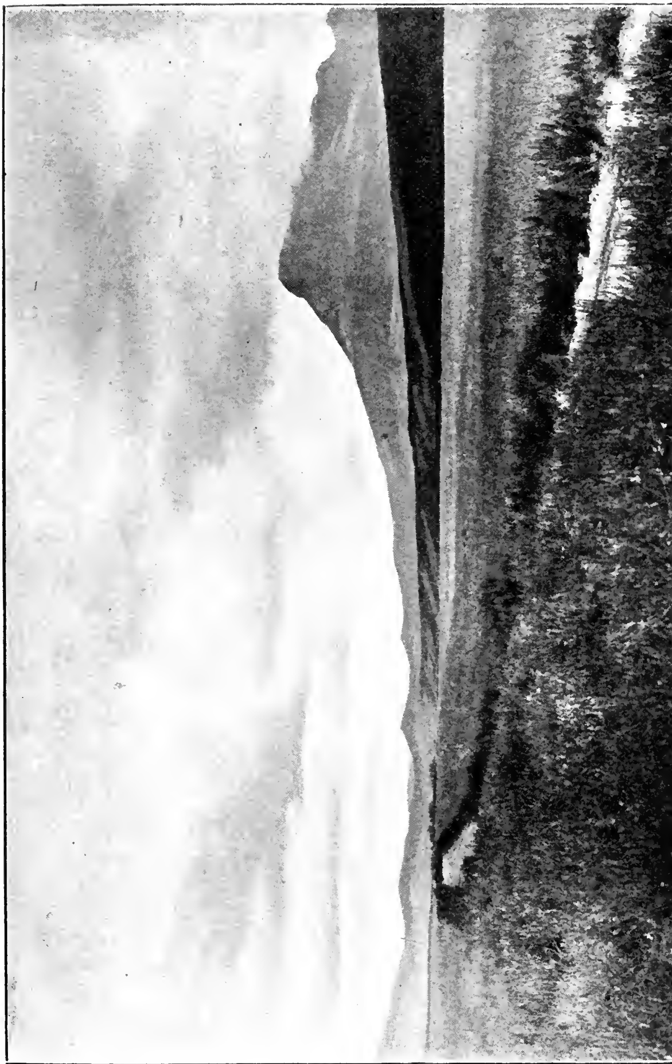


Plate VI.—View in the Cold Bokkeveld showing succession from the Table Mountain sandstone of Schurfteberg (on the left) to the Witteberg beds on the Tafel Berg (on the right). The ridge on the right of the foreground is the escarpment of the first or fossiliferous sandstone of the Bokkeveld beds.

short distance. In the view shown in Plate VI., taken on the west side of the Schurfteberg (north) anticline (Cold Bokkeveld), looking south, the escarpment of the fossiliferous sandstone is seen on the right of the road as a low ridge, and also on the horizon. The top of the Table Mountain series is seen on the left of the picture as a long slope with one slight protuberance; the lowest part of the ridge, at a spot above which some more distant hills appear, is formed by the lowest shales of the Bokkeveld that also occupy the flat valley in which the road lies; the higher groups of sandstone beds in the Bokkeveld series make ridges on the horizon, but the fourth sandstone is very slightly marked; the high mountain on the right is the outlier of Witteberg beds named Tafel Berg. Plate VII., taken at Riet River in the Cold Bokkeveld, illustrates the succession on the east side of the Cederberg anticline; in the foreground is the Table Mountain sandstone dipping east under the Bokkeveld of the high hills (Blink Berg) in the middle of the picture, which are capped by the Witteberg beds. The top of these hills is about 2,000 feet above the bottom of the valley. The four groups of sandstone in the Bokkeveld series appear as kranzes on the face of Blink Berg, and the three lower ones are well seen on the sky-line. The position of the shales below the fossiliferous sandstone is almost invariably marked by a valley along which a road runs. This is the case along the Cederbergen and Cold Bokkeveld Mountains, in the Hex River Valley, in the country north of the Zwartebergen, and in much of the country between the Hex River Valley and the Gouritz River Poort. The fossils

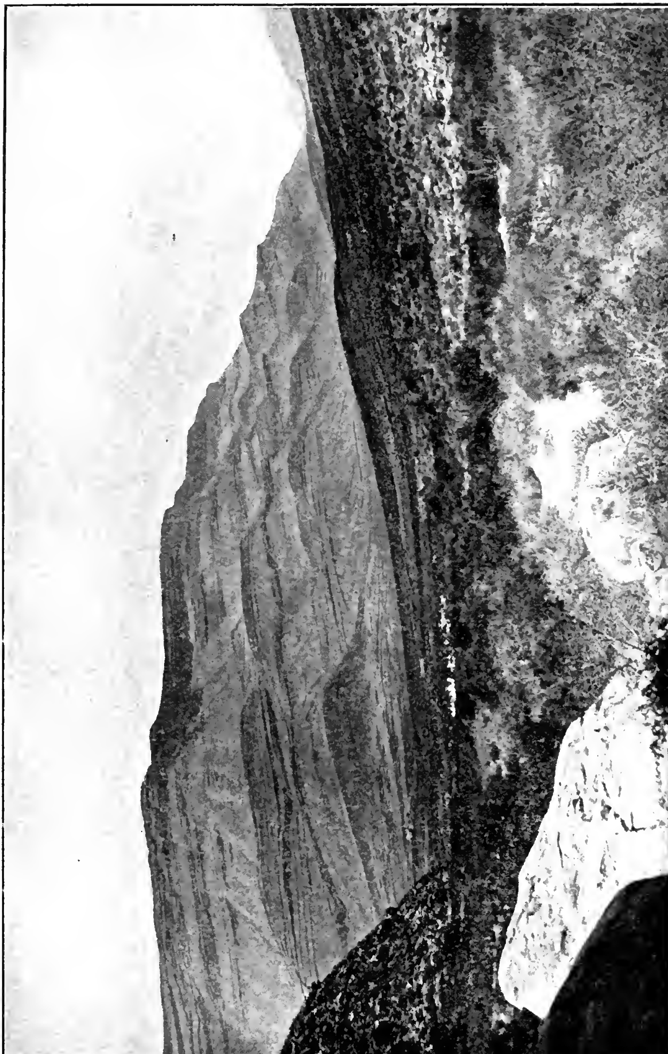


PLATE VII.—Blink Berg in the Cold Bokkeveld. Table Mountain sandstone in the foreground; krantzes of the Bokkeveld sandstones are seen on the slope of Blink Berg, which is crowned by the Witteberg beds.

in the sandstone are usually in the form of impressions left by the removal of the calcareous shells. The shells themselves are rarely seen in the rock taken from near the surface of an outcrop, but when the rock from a distance of some feet from a weathered surface is obtained, the calcite shells are often seen in it. The sandstone itself is slightly calcareous, but beds of limestone are of very rare occurrence.

Above the fossiliferous sandstone is the second group of shales containing fossils, from 100 to 300 feet thick. In the Cold Bokkeveld area the second group of shales is distinguished by the presence of star-fish, but many of the species that occur in the lower group are found here also. Above them is the second sandstone, which weathers into light-coloured outcrops, differing strongly in this respect from the first or fossiliferous sandstone; it contains few fossils; *Spirifer* is occasionally abundant. The second sandstone is a thick group with many shale beds, and in the Gamka Poort section reaches a thickness of 400 feet.

The third group of shales is about 350 feet thick, the beds are often micaceous, and have thin quartzites interbedded with them; they usually contain few fossils, *Nuculites* occurs in them at the Gamka Poort. Near the Tunnel Siding on the Hex River line this group of shales yielded *Lingula, Nuculites,* crinoid stems, a trilobite and *Conularia,* and also some badly preserved plant stems resembling *Lepidodendron.* The third sandstone group (100 feet) with the shales above (300 feet), as well as the fourth sandstone (100 feet) and the overlying shales (500 feet), have not been found to contain fossils other than badly preserved plant remains. These are not so well defined as the lower groups, and both the shales and sandstones are often very micaceous. The fourth shale group is taken as the uppermost of the Bokkeveld series, and the beds in it often closely resemble those belonging to the Witteberg. The division between these two series is an arbitrary one, and cannot be laid down with certainty in the absence of a clearly exposed succession from below. In the country north of the Zwartebergen, in the Cold Bokkeveld, and in the Hex River-Ladismith Karroo district, there is not much difficulty in fixing upon a boundary which is probably at one and the same horizon throughout; but south of the Langebergen the task is an impossible one, and the limits of the Witteberg beds there as laid down upon the map must be considered as only roughly correct.

Along the northern slope of the Langebergen the Bokkeveld beds are very much cleaved; the cleavage planes have a constant and high inclination to the south, while the dip of the beds is very variable in amount, and in direction is either nearly north or south, the strike of the beds being nearly east and west, parallel to the cleavage. There is usually no difficulty in distinguishing between the bedding planes and cleavage in this district, for the sandy portions of the rock resist the weather better than the finer grained beds, and stand out more or less prominently on the hill-sides. South of the Langebergen, however, especially east and south of the Robertson Division, the distinction between the two sets of divisional planes is much less marked,

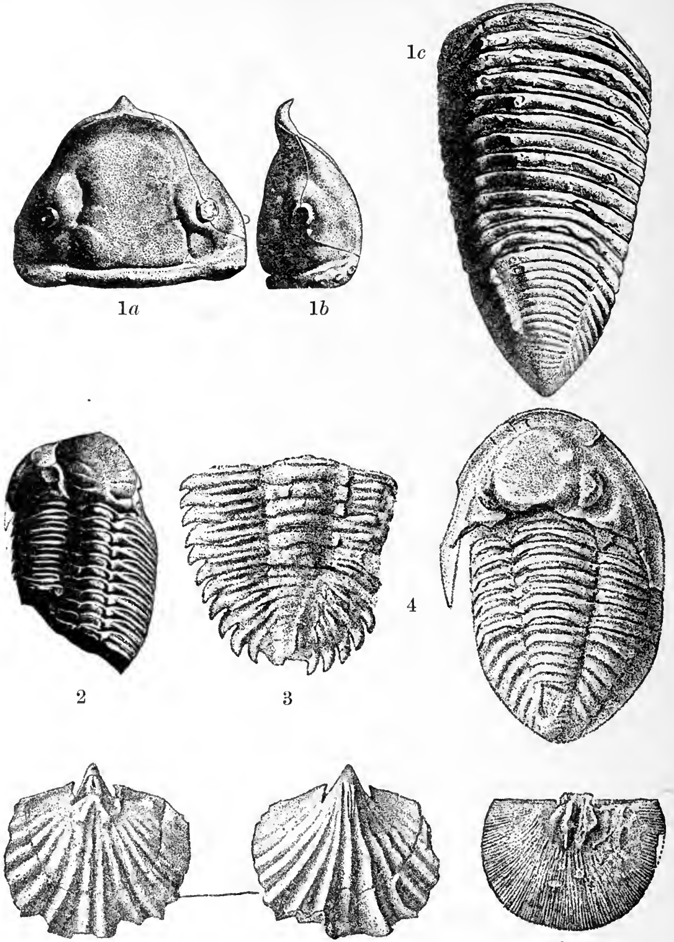
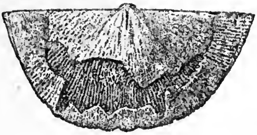


Fig. 11.—Fossils from the Bokkeveld beds.

1a. } *Homalonotus herscheli*, head. Half natural size.
1b. }
1c. ,, ,, body and tail.
2. *Phacops africanus*. Half natural size.
3. ,, *caffer*. Natural size.
4. *Proetus malacus*. Natural size.
5. *Leptocœlia flabellites*. Two-thirds natural size.
6. *Orthothetes sulivani*. Two-thirds natural size.



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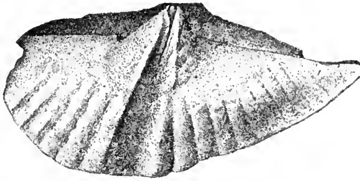

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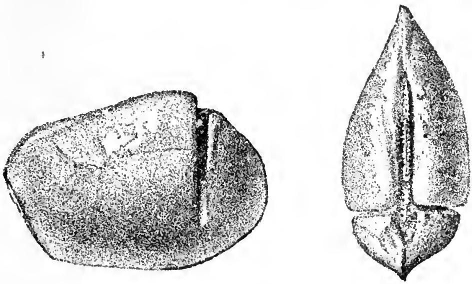

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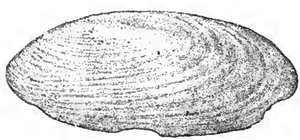

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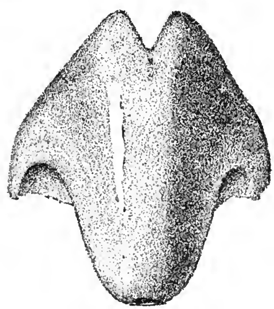

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7. *Chonetes falklandicus.* Two-thirds natural size.
8. *Spirifer orbignyi.* Half natural size.
9. *Nuculites branneri.* Natural size.
10. *Glossites* aff. *depressus.* Half natural size.
11. *Actinopteria* aff. *boydi.* × One and a half.
12. *Bellerophon salteri.* Natural size.

1 and 2 from Salter, 3 and 4 from Lake, 5-12 from Reed.

partly owing to the strong development of the cleavage, but partly on account of the more uniformly fine-grained nature of the rocks. Few fossils have been found in the Bokkeveld beds south of the Langebergen, probably because those contained in the slates are so much distorted by pressure that they are not easily recognisable. In the small synclines of these beds, folded in amongst the Table Mountain series in the Knysna Division, several genera have been obtained; on the Keurboom's River *Orthoceras, Phacops, Orbiculoidea, Leptocœlia, Chonetes, Spirifer, Nuculites, Bellerophon, Tentaculites* and crinoids have been found. Farther west a few characteristic species have been obtained from the Bredasdorp, Caledon and Worcester Divisions, but they are usually greatly distorted.

The distinctly finer grained nature of the Bokkeveld beds south of the Langebergen than to the north of those mountains points to the position of the shore-line of the sea in which they were deposited having crossed South Africa in a general east and west direction to the north of the area now occupied by them. It is not possible to determine the position more closely, for the northern limit of the beds is only seen in the west of Calvinia, and is there an eroded surface of great age; the denudation which swept away the in-shore portion of the Bokkeveld beds took place in the Pre-Dwyka times, and the greater part of the northern limit is still buried beneath the Karroo formation between the Oorlog's Kloof River west of Calvinia and the submerged south-eastern portion of the folded belt off the south-east coast.

The marine fossils that occur in the lower half of the Bokkeveld series afford sufficient evidence that the rocks in which they are embedded were deposited under the sea; and the frequent occurrence of false-bedding in the sandstones throughout the series points to deposition in shallow water. The bottom of the sea must have been slowly sinking to allow such an accumulation of shallow water sediments, although some of the shales may have been formed in deeper water. In the upper part of the Bokkeveld series no marine forms have been noticed; a few indistinct plants are the only fossils that have been found in them. It is difficult to explain the absence of marine animals if the conditions under which these rocks were formed remained the same as before; and the absence of marine fossils from the succeeding 2,500 feet of the Witteberg sandstones and shales warrants the supposition that the conditions which prevailed in the area now called Cape Colony during early Bokkeveld times changed from marine to fluviatile or lacustrine after the deposition of the third shale group, and remained so throughout the later Bokkeveld and the whole of the Witteberg periods.

The following is a list of fossils obtained from the Bokkeveld beds :—

	Falkland Islands.	South America.	North America.	Europe.
WORM TUBE—				
Serpulites sica, Salter	...	...	...	...
CORAL—				
Zaphrentis zebra, Schwarz	...	...	...	...
OPHIUROIDS (undetermined)	...	...	...	...
CRINOID—				
Ophiocrinus stangeri, Salter	...	...	...	...
TRILOBITES—				
Phacops africanus, Salter	...	*a*	...	...
,, *acacia*, Schwarz	...	...	...	...
,, *arbuteus*, Lake	...	*a*	...	...
,, *cristagalli*, Woodward	...	...	...	...
,, *impressus*, Lake	...	...	...	...
,, *ocellus*, Lake	...	...	...	...
,, *pupillus*, Lake	...	...	...	...
,, (*Cryphaeus*) *caffer*, Salter	...	*a*	...	...
,, ,, *callitris*, Schwarz	...	...	...	...
,, ,, *ceres*, Schwarz	...	*a*	...	...
,, ,, *gydowi*, Schwarz	...	...	...	...
Dalmanites lunatus, Lake	...	...	...	...
Proetus malacus, Lake	...	...	...	...
Typhloniscus baini, Salter	...	...	...	...
Homalonotus agrestis, Schwarz	...	...	...	...
,, *colossus*, Lake	...	...	...	...
,, *herscheli*, Murchison	...	*a*	...	...
,, *hippocampus*, Schwarz	...	...	...	...
,, *horridus*, Schwarz	...	...	...	...
,, *lex*, Schwarz	...	...	...	...
,, *perarmatus*, Frech	...	...	...	...
,, *quernus*, Lake	...	...	...	...
BRACHIOPODS—				
Lingula, aff. *densa*, Hall	...	*a*	*a*	...
Orbiculoidea baini, Morris and Sharpe	×	×	*a*	...
Stropheodonta, cf. *concinna*, Morris and Sharpe	×	...	*a*	...
Strophonella, sp. Reed	...	*a*	*a*	...
Orthothetes sulivani, Morris and Sharpe	×	*a*	*a*	...
Chonetes falklandicus, Morris and Sharpe	×	×	...	...
,, cf. *coronatus*, Conrad	...	*a*	*a*	...
,, cf. *arcei*, Ulrich	...	*a*	...	...
,, aff. *setiger*, Hall	...	...	*a*	...
Orthis ? sp. Reed	...	*a*	*a*	...
Rhynchonella (*Camarotoechia ?*), sp. Reed	...	...	*a*	...
Rensselaeria relicta, Schwarz	...	...	*a*	...
,, cf. *confluentina*, Fuchs	...	...	...	...
,, (*? Rhynchospira*) *hottentot*, Schwarz	...	...	...	...

	Falkland Islands.	South America.	North America.	Europe.
BRACHIOPODS (*continued*)—				
Rensselaeria montaguensis, Reed	...	...	*a*	*a*
,, cf. *cayuga*, Hall and Clarke	...	...	*a*	...
,, aff. *stewarti*, Clarke ?	...	...	*a*	...
,, sp. *β*, Reed	...	...	*a*	...
Trigeria, aff. *gaudryi*, Oehl	...	...	*a*	...
,, (? *Rhynchospira*) *simplex*, Schwarz	...	...	...	...
,, ? cf. *silveti*, Ulrich	...	...	...	...
Cryptonella baini, Sharpe	×	*a*	*a*	...
Spirifer orbignyi, Morris and Sharpe	×	×	*a*	...
,, *ceres*, Reed	...	*a*	*a*	...
,, cf. *pedroanus*, Hartt	...	*a*	*a*	...
,, sp. *α*, Reed	...	...	*a*	...
,, sp. *β*, Reed	...	...	...	...
Ambocoelia umbonata, Conrad	...	...	×	...
Retzia, cf. *adrieni*, De Vern	...	*a*	...	...
Leptocoelia flabellites, Conrad	×	×	×	...
Scaphocoelia ? africana, Reed	...	*a*	...	...
,, ,, var. *elizabethae*, Reed	...	...	...	...
Ptychospira variegata, Reed	...	...	...	...
Vitulina pustulosa, Hall	...	×	×	...
? Tropidoleptus carinatus, Conrad	...	×	×	×
LAMELLIBRANCHS—				
Nuculites abreviatus, Sharpe	...	...	...	...
,, *africanus*, Salter	...	*a*	...	...
,, *branneri*, Clarke	...	×	...	*a*
,, ,, var. *obtusus*, Reed	...	*a*	...	...
,, *beneckei*, Ulrich, var.	...	*a*	...	...
,, *pacatus*, Reed	...	...	*a*	...
,, *sharpei*, Reed	...	...	...	...
,, *capensis*, Reed	...	...	*a*	*a*
,, *colonicus*, Reed	...	...	...	...
,, *lunata*, Schwarz	...	...	...	...
,, *martialis*, Reed	...	...	*a*	...
,, *? ovatus*, Sharpe	...	...	...	...
,, cf. *smithi*, Clarke	...	*a*	*a*	...
Palaeoneilo antiqua, Sharpe	...	...	...	...
,, *? arcuata*, Schwarz	...	...	...	...
,, *boyesi*, Schwarz	...	...	*a*	...
,, *rudis*, Sharpe	...	...	...	...
,, *subantiqua*, Reed	...	...	...	...
,, aff. *constricta*, Conrad	...	...	*a*	...
,, cf. *fecunda*, Hall	...	...	*a*	...
Nuculana inornata, Sharpe	...	*a*	*a*	*a*
,, *viator*, Reed	...	*a*	*a*	*a*
,, *agrestis*, Reed	...	...	...	...
Nucula nigella, Reed	...	...	*a*	...
Buchiola subpalmata, Reed	...	...	*a*	*a*
Cardiomorpha campestris, Reed	...	...	...	...

	Falkland Islands.	South America.	North America.	Europe.
LAMELLIBRANCHS (*continued*)—				
Praecardium ? sp. Reed	...	...	...	...
? Cypricardella pohli, Clarke	...	×	...	...
Anodontopsis ? rudis, Sharpe	...	...	...	...
Orthonota, aff. *undulata*, Conrad	...	...	*a*	...
Grammysia corrugata, Sharpe	...	*a*	...	...
,, *montana*, Reed	...	...	...	...
Sanguinolites niger, Reed	...	...	...	*a*
,, *? acer*, Reed	...	...	...	...
Glossites, aff. *depressus*, Hall	...	...	*a*	...
Nyassa arguta, Hall	...	...	×	...
Solenopsis ? bokkeveldensis, Reed	...	...	*a*	*a*
Leptodomus ? fontinalis, Reed	...	...	...	...
Modiomorpha baini, Sharpe	...	...	*a*	...
,, ,, var. Reed	...	...	...	...
,, cf. *pimentana*, Hartt and Rath	...	*a*	...	...
,, aff. *sellowi*, Clarke	...	*a*	...	...
Byssopteria ? sp.	...	...	...	...
Actinopteria, aff. *boydi*, Conrad	...	*a*	...	*a*
,, aff. *humboldti*, Clarke	...	...	*a*	...
GASTEROPODS—				
Pleurotomaria, aff. *kayseri*, Ulrich	...	*a*	*a*	...
Metoptoma capense, Reed	...	...	...	...
Bellerophon quadrilobatus, Salter	...	*a*	...	...
,, (*Bucaniella*), aff. *trilobatus*, Sow	...	...	...	*a*
,, ,, cf. *reissi*, Clarke	...	*a*	...	...
,, cf. *morganianus*, Hartt and Rath	...	*a*	...	...
,, (*Plectonotus*), aff. *salteri*, Clarke	...	*a*	...	...
,, ,, *fraternus*, Reed	...	...	...	...
,, (*Tropidocyclus*), cf. *gilletianus*, Hartt and Rath	...	*a*	...	...
Loxonema, sp.	...	...	*a*	...
Holopea baini, Sharpe	...	...	...	...
Diaphorostoma ? sp.	...	...	...	...
PTEROPODS—				
Tentaculites crotalinus, Sharpe	...	*a*	*a*	...
,, *baini*, Reed	...	*a*	...	...
Hyolithes subaequalis, Salter	...	*a*	*a*	...
Conularia africana, Sharpe	...	×	*a*	...
,, *quichua*, Stein. Död	...	×	...	...
,, cf. *undulata*, Conrad	...	*a*	*a*	...
,, cf. *acuta*, Roem	...	*a*	...	*a*
CEPHALOPODS—				
Orthoceras gamkaensis, Reed	...	*a*	...	...
,, *bokkeveldensis*, Reed	...	...	*a*	...
,, *rex*, Schwarz	...	...	...	...
FISH SPINE—				
Machaeracanthus, sp. ?	...	...	...	...

The fossils[1] common to the Bokkeveld beds and the Devonian strata of the Falkland Islands, South and North America, and Europe are marked with a cross, ×, and "*a*" indicates that the species is very closely related to one or more in those countries. The general character and relationship of the fauna have lately been discussed by Mr. Reed in the first paper mentioned in the footnote. He points out that the fauna is remarkably poor in corals and cephalopods, and that it is more nearly related to that of the Devonian strata of South America than of other parts of the world. The relationship with the North American Devonian fauna is also very close, the relationship being with the Middle rather than with the Lower Devonian; in the case of European faunas the resemblance is closer to the Lower Devonian (Coblenzian).

The similarity to the American fauna and the contrast to the probably contemporary fauna in Europe has led several authors to postulate the existence of a continent[2] between America and Africa, over part of what is now the Atlantic Ocean, during Devonian times; this land barrier separated the southern sea from that of Western Europe. This hypothesis, however, is only one of

[1] The list of fossils is taken from Mr. F. R. C. Reed's paper in *G. M.*, 1907, pp. 167, 222, with additions from the same author's latest paper in *A. S. A. M.*, vol. iv., 1908, p. 381. The species mentioned are described in the following papers: Salter and Sharpe, *T. G. S.*, 2nd series, vol. vii., 1856, p. 203; Woodward, *Q. J. G. S.*, xxix., 1873, p. 31; Lake, *A. S. A. M.*, vol. iv., 1904, p. 201; Reed, *A. S. A. M.*, vol. iv., 1903, p. 165, and *ibid.*, iv., 1904, p. 239; iv., 1908, p. 381; *G. M.*, 1907, p. 34, and Schwarz, *Rec. Alb. Mus.*, i., 1906, p. 347.

[2] This is the Flabellites Land of Prof. Schwarz, *T. S. A. P. S.*, xvi., p. 19.

several possible explanations. The faunas compared were of littoral habit and may have been effectually separated by a deep ocean, and there may also have been climatic reasons for the diversity. Other evidence for the existence of an Atlantic continent is seen in the distribution of late Mesozoic and early Cainozoic fossils, terrestrial as well as marine; and also from supposed remnants of continental rocks thrown from the volcanoes of the Atlantic Islands, and from the serpentines of St. Paul's Rocks, but it has not been proved that the land was continuous at any one time, nor is the evidence from the rocks independent of theoretical considerations as to the nature of the sub-oceanic crust.

The recent discovery in the Sahara of Devonian fossils said to be identical with, or closely related to, Cape and American forms[1] (*Homalonotus herscheli*, *Leptocœlia flabellites*, *Conularia africana*, *Actinopteria* aff. *boydi*) is not in agreement with the hypothesis of a continent which prevented communication between the southern and northern seas. At present, therefore, the question must be regarded as an open one.

The country occupied by the Bokkeveld beds north of the Langebergen and in the Worcester and Robertson Divisions south of that range is characterised by strongly marked escarpments and valleys, so that from the top of a prominent hill in a suitable position the lie of the rocks can be made out over a very wide area. The most accessible of such hills are the Brand Vlei Mountain near Worcester, Gydo Berg north of Ceres, the high hill

[1] Haug, E., *Comptes Rendus*, cxli., 1905, p. 970.

near Triangle, in the Hex River Valley, and the top of the hill east of the north entrance to Seven Weeks' Poort. The last-named spot is one of the finest points of vantage in the Colony for the purpose of seeing the structure of a wide area. The folds into which the rocks have been thrown north of the Zwartebergen are distinctly seen, the outcrop of the four groups of sandstone in the Bokkeveld series make independent escarpments or ledges on large ridges, and where repeated by folding the structure is seen clearly. The gradual dying out of the folds northwards in the Karroo is displayed as if the country were a geological model, and the outcrops of each formation are at once recognised. The sandstones and quartzites of the Bokkeveld and Witteberg series stand up prominently between the shale bands that have determined the positions of the minor valleys, the soft, easily eroded shales having offered an easier path for the rivers than the more resistant sandstones. The view is limited on the north by the great dolerite-crowned escarpment of the Nieuweveld, seventy miles distant.

South of the Langebergen the structure of the country is not at all obvious until it has been made out in detail, for the Bokkeveld beds have been cut to a level with the outliers of the Uitenhage series; and although this plain has since been dissected by rivers, the Bokkeveld and Witteberg slates, on account of their uniform character, have had little effect in determining the positions of the valleys, so that the longitudinal valleys so conspicuous north of the mountains are not nearly so well developed to the south.

The Bokkeveld beds do not furnish any stone or minerals of much economic value. The sandstones are used for making walls round kraals and camps, and to a small extent for house-building on farms. Their colour is too dark and patchy, and as a rule they are too fissile and difficult to work to be used when any other building materials are obtainable.

The country occupied by this series is generally well populated, for the soil is rich. The shales break down into good soil, hence the positions of the thicker bands of shale are usually marked by lands and gardens, often with a dip slope of the Table Mountain sandstone on the one hand and an escarpment of the Bokkeveld sandstones on the other.

Springs are more numerous along the junction of the Table Mountain sandstone and the Bokkeveld beds than elsewhere in the neighbourhood, and although many of the springs yield "kruid water," *i.e.*, water with the smell of sulphuretted hydrogen, due to the mutual decomposition of pyrites and the organic matter in the shales in the presence of moisture, they are very valuable sources of water. This peculiarity of the water is the cause of so many farms being called "Stink Fontein," a name that recurs again and again on the Bokkeveld areas as well as on other rocks, such as the Dwyka and Ecca beds, the water from which has frequently the same characteristic.

3. The Witteberg Series.

The Witteberg series consist of sandstones, quartzites, and shales. The sandstones and quartzites are in thicker groups than those of the Bokkeveld beds, and occasionally contain thin beds of white quartz pebbles, and also isolated pebbles of the same material. The resemblance between the Witteberg quartzites and the Table Mountain beds was the cause of much confusion in the early days of Cape geology, but it is more apparent than real. The Witteberg quartzites, as a whole, have a more reddish and yellow tint and are more micaceous than the Table Mountain rock, and they are much less massive, shale bands being of comparatively frequent occurrence. The shales are green, dark grey and blue in colour, and they are often very micaceous and sandy, frequently being more properly called thin, irregularly bedded micaceous sandstones than shales. In the Eastern Province there are black carbonaceous shales, which are different from any beds in this series that have been found in the west. The Witteberg beds have so far yielded no remains of animals, and only rather poor specimens of plants which have not been satisfactorily determined for want of good material.

The following genera of plants have been mentioned[1] as having been found in the Witteberg beds:—

Didymophyllum	Willowmore.
Selaginites	Port Alfred.
Lepidodendron	Grahamstown, Swellendam and Riversdale.
Lepidostrobus	Port Alfred.
Halonia	,,
Knorria	Swellendam.
Sigillaria	Port Alfred.
Stigmaria	,,
Cyclostigma	Many places in the west of the Colony.
Bothrodendron	Albany district.

[1] This list is taken from Feistmantel, *Abh. der König. böhm. Gesellschaft der Wiss.*, vii. Folge, 3 Bd., 1889, and Schwarz, *Rec. Alb. Mus.*, i., p. 247.

Little value can be set upon the determinations in the above list, but it is of interest to note that all the genera occur in the carboniferous rocks of Europe, and the *Cyclostigma* is very like a fossil described by Feistmantel from the Goonoo-Goonoo beds (Devonian or Carboniferous) of New South Wales.

By far the most abundant fossil, if it be one, is *Spirophyton*, but Prof. Seward,[1] who has examined some of the specimens collected by the Cape Survey, is of opinion that these markings are not of organic origin.

Spirophyton is found as an impression extending spirally through several inches of rock, with the curved striations radiating from a central depression to a peripheral groove. It is difficult to understand how such a well-defined structure with a sharply marked limit passing spirally through several layers of sediment can be produced by mechanical means, such as the swirling of water through a hole in the sand. No carbonised remains of vegetable matter have been found adhering to the surface of the *Spirophyton* impressions, but the same is the case with the undoubted plant impressions, from the Witteberg and Bokkeveld beds in the west of the Colony.

Whether a true fossil or not, *Spirophyton* has been found of great service in enabling the Witteberg beds to be recognised, as it is doubtful whether it occurs in the uppermost Bokkeveld beds, and it has never been found in the Dwyka or later rocks. It is met with in hard quartzites and in shales; the best specimens are those from the quartzites; the markings are better pre-

[1] Seward, *A. S. A. M.*, iv., p. 103.

served in quartzite than in the micaceous and sandy shales, although they are more abundant in the latter.

The Witteberg beds have a maximum thickness of about 2,500 feet. They form several important ranges of mountains on the southern border of the Karroo, and their name is taken from the Wittebergen, south of Matjes Fontein. In the west and south of the Colony the mountains composed of the Witteberg beds are remarkably bare and barren-looking (see Plate VIII.). They are less well supplied with rain than the Table Mountain sandstone ranges, for the latter are generally higher and therefore receive a heavier rainfall. The high percentage of quartz sand in the Witteberg beds causes the soils derived from them to be poor and thin. The formation is first met with in the west of the Colony, north of Eland's Vlei (Calvinia and Clanwilliam), where the long line of hills called the Zwart Ruggens commences. The northern boundary is a denuded one, and, as is the case with the Bokkeveld boundary a little farther to the north, is of great antiquity, being chiefly older than the Dwyka series. Following the Witteberg beds southwards they become thicker owing to the coming in of higher and higher beds below the Dwyka. Some outliers, somewhat table-shaped mountains, are found at Bidouw, Gerustheid, and in the angle between the Bosch and Doorn Rivers in the north-east of Clanwilliam and south-west of Calvinia. The Zwart Ruggens are a long dip slope of the quartzites on the east of the Cederberg and Cold Bokkeveld anticlines. When seen from the Karroo the Zwart Ruggens appear to consist entirely of whitish

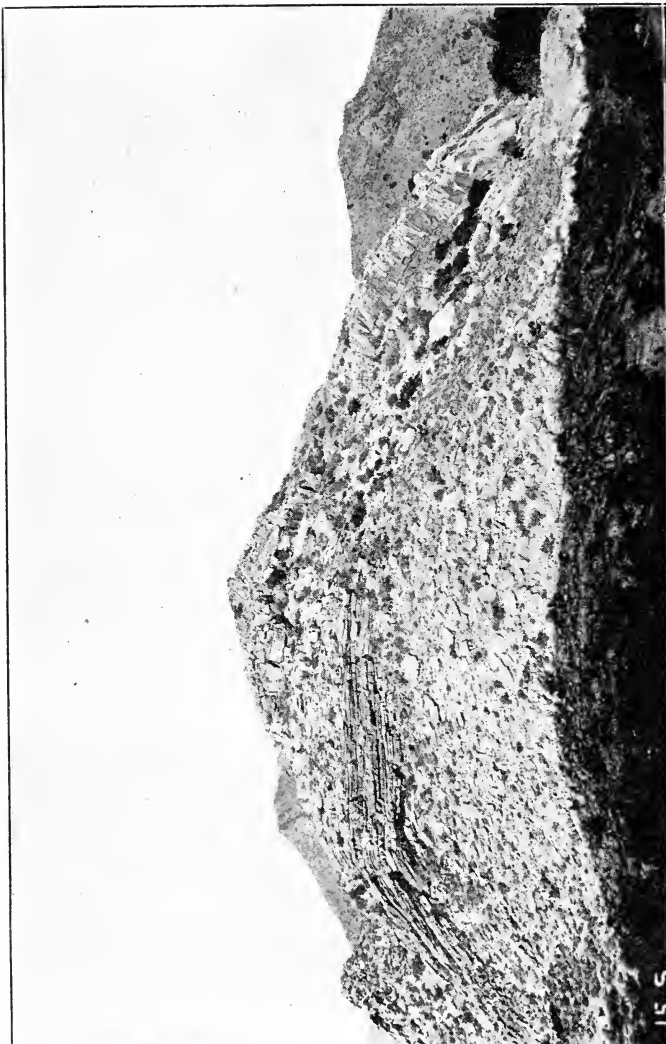


PLATE VIII.—An anticline in the Witteberg beds at Tygerberg in Prince Albert.

quartzites, for the numerous shale bands are more easily weathered away and can only be seen when one enters a ravine or gorge, such as the Tra-Tra or Winkelhaak's (Doorn) River valleys, which drain the Cold Bokkeveld. The Zwart Ruggens merge into the Bonteberg Range at Karroo Poort, when the strike of the rocks changes from south to east. The axis of the Bonteberg anticline is inclined eastwards, so that the Dwyka series sends a tongue west-south-west towards Pienaar's Kloof north of Touw's River Station. The Witteberg beds are continued across Pienaar's Kloof into the Voetpad Berg, and also round the south of the Quarrie Kloof Dwyka outlier into the Wittebergen. In the southern part of the Worcester Division the Witteberg beds form a V-shaped area; the two arms of the V meet on the south and are cut off by the Worcester fault to the north, but the western junction is buried beneath the conglomerates of the Uitenhage series; the apex of the V is at Roode Berg near the road between Villiersdorp and Worcester. In Robertson the Witteberg beds form an area about twenty-four miles in length, south of the fault; and they also occur in Swellendam and Riversdale. To the north-east of Montague they form two synclines connected at the eastern end; Klein Berg is part of the southern syncline, and the hills near Dobbel Aars Kloof belong to the northern one.

Between the Bonteberg and Matjes Kop these beds cover a considerable area, over forty miles long and twenty wide in places, being thrown into many small folds, and in four of the synclines or troughs outliers of the Dwyka series occur; the Nauga and Coega (or

Kouga) hills are in this area. The axis of the main anticline of the Wittebergen disappears eastwards south of Laingsburg, where a long syncline of the Dwyka series lies south of the eastern part of the range. The Witteberg beds pass round the western end of the Dwyka syncline into Eland's Berg, which disappears eastwards in a similar manner to the Wittebergen, but the beds pass round another westerly rising Dwyka syncline into the long range of foothills north of the Zwartebergen, and extend far to the east, certainly as far as Willowmore; they reappear from under a syncline of the Dwyka series in the Groot River and Klein Winterhoek ranges to the north. East of the Klein Winterhoek Mountains the Witteberg beds form the Zuurbergen, the hills near Commadagga, Botha's Hill and the hills south of Grahamstown, and much of the country between Grahamstown and the coast.

The Witteberg country in the Eastern Province is much better covered with vegetation than that in the west, chiefly on account of the greater rainfall, but possibly the eastern rocks are somewhat more argillaceous and less quartzitic than the western, and therefore give rise to better soils. Whether the Witteberg series as a whole becomes finer grained towards the east is still uncertain, for it has not been closely examined in that part of the country.

To the south of the Langebergen and east of Robertson the Witteberg beds are distinctly less quartzose and coarse grained than to the north of that range; a change takes place in them similar to that noted in the Bokkeveld series, as they are followed southwards. It has been stated previously that the absence of marine fossils from the Witteberg beds must be regarded as evidence that these sediments were not laid down under the sea, but they may have been formed in fresh water. The settlement of this question must always be a difficult task, and the rocks must be known in much greater detail than they are at present before it can be accomplished. False bedding and rippled surfaces are frequently seen in these rocks, which were certainly laid down in shallow water not far from the land.

There can be little doubt that the Witteberg beds once extended over the whole of the southern and western portion of the Colony. The position of the land from which the sediments were derived is as problematical as the position of the Bokkeveld coast line. From the fact that the coarse sediments are found in the northern exposures, it must be concluded that the land lay in that direction, and it probably lay farther south than the Bokkeveld shore.

The Witteberg beds have no economic importance. The presence of black coaly shales in the Witteberg series on the Kowie River led to prospecting for coal some forty years ago, but without success. A great part of the country occupied by this series is very rugged, owing to the quartzite bands standing out prominently from the general surface. The white quartzites often give rise to great bare stony dip slopes, such as those on the eastern side of the Zwart Ruggens west of the Karroo and in the mountains south of Matjes Fontein.

CHAPTER VII.

THE KARROO SYSTEM.

Beds belonging to the Karroo system cover the greater part of the Cape Colony; from a line between Karroo Poort and the Gualana River mouth (Peddie) they stretch northwards and occupy the central and eastern portions of Cape Colony, while a large outlier occurs north of the Orange River in Gordonia. For hundreds of miles they are practically the only rocks exposed at the surface with the exception of the intrusive dolerites. Somewhat monotonous from the repeated occurrence of sandstones, shales and mudstones, in all thousands of feet thick, and from the fact that they generally dip at so low an angle that in the absence of considerable changes of level in the surface a comparatively thin group of beds occupies a very wide area, nevertheless they are of great interest from several points of view. Perhaps their chief interest consists in the reptilian remains preserved in them, and in the similarity of their fossil plants to those found in the Gondwana system of India and in certain beds in Australia and South America.

At present the system is subdivided as follows in descending order:—

			Approximate maximum thickness.	
Karroo system	Stormberg series	Drakensberg beds (volcanic)	4000	8400
		Cave sandstone . . .	800	
		Red beds	1600	
		Molteno beds . . .	2000	
	Beaufort series	Upper (Burghersdorp) beds		6000
		Middle		
		Lower		
	Ecca series	. . . .		2600
	Dwyka series	Upper shales . . .	600	2300
		Boulder-beds . . .	1000	
		Lower shales . . .	700	
				19,300

The maximum thickness of the Karroo formation is not less than 15,000 feet, excluding the volcanic beds, although it is uncertain whether the full thickness is now, or ever was, developed in any one locality. This great bulk of sedimentary rocks nowhere contains evidence of marine conditions having prevailed during its deposition; on the contrary, nearly all the fossils known from the Karroo beds were undoubtedly land or fresh-water forms. The accumulation of so great a thickness of beds under such conditions is a very interesting fact, and we shall return to the subject in a later chapter.

1. The Dwyka Series.[1]

Everywhere round the borders of the central basin a rock with very peculiar characters crops out. For a long time it was more or less of a puzzle to geologists, and the formation was given such names as "trap-conglomerate" or claystone-porphyry," and by some observers was considered to be of sedimentary and by

[1] A full historical account of the views regarding the nature of the Dwyka will be found in Corstorphine, "The History of Stratigraphical Investigation in South Africa," *Rept. S. A. A. S.*, 1904, p. 153.

PLATE IX.—Dwyka tillite, cliff on right side of ravine about 2½ miles from Prieska on Kenhardt road. The irregular distribution of large and small rock fragments through the sandy mudstone is characteristic. The hammer handle is 14 inches long.

others of volcanic origin. The name "Dwyka Conglomerate" was introduced by Dunn from the occurrence of the formation on the Dwyka River near Prince Albert, and this term has been almost universally adopted.

The rock is typically blue or greenish in colour, compact and fine grained, and made up of small particles of sand, which under the microscope are seen to be chiefly quartz and microcline, with a smaller quantity of other felspars, epidote, garnet, calcite and other minerals, embedded in a very fine-grained argillaceous material. This "sandy mud" contains a vast number of boulders and pebbles of an immense variety of rocks, amongst which are conglomerates, quartzites, sandstones, shales, slates, crystalline limestones, jaspers and banded ironstones, granites and gneisses, diabases and amygdaloidal lavas, quartz porphyries, serpentines, etc., the nature of the inclusions varying in different localities.

These boulders are, as a rule, scattered irregularly through the matrix; only in rare instances are they arranged in one or more well-defined layers. Plate IX., from a photograph of the rock exposed in a ravine near Prieska, gives a good idea of the manner in which the pebbles and boulders usually occur.

Not only is the great variety in composition and size of the boulders remarkable, but a large proportion of them have scratched and striated surfaces, while in many there are one or more striated flattened faces giving a roughly facetted form to the pebbles. In all respects these boulders are similar in form and in the nature of their striations to the scratched boulders that are found in the moraines of modern glaciers and in the ancient boulder-clays (tills) and moraines of Northern Europe and America, countries that are no longer so extensively covered with ice and snow as they used to be.

Had the striated boulders in the Dwyka boulder-beds belonged to a less remote geological period than the Palæozoic era, no doubt would have been cast upon the glacial origin of their peculiarities and of the striated surfaces upon which the boulder-beds frequently rest, but geologists were reluctant to admit that glacial conditions could have prevailed so long ago in countries that now enjoy temperate and sub-tropical climates.

With time and increase of knowledge the existence of glacial conditions in the Palæozoic era, and in what are now temperate or tropical latitudes, has been generally admitted, and year by year the accumulation of evidence bearing upon the origin of the Dwyka, and similar boulder-beds in South America, Asia, and Australia show more and more forcibly that glacial action is the only agency capable of explaining the formation of these deposits.

The use of the term "conglomerate" to describe the boulder-beds is not satisfactory, for the boulders and pebbles are rarely so abundant as to bring the rock within the usual definition of a conglomerate. The rock is too hard, as a rule, to be termed a boulder-clay, while the terms moraine and ground moraine are hardly justified until we know more about the conditions under which the deposits were formed. To obviate these difficulties and to avoid the rather cumbersome phrase "hardened boulder-clay," Prof. Penck suggested the term "tillite," a handy word, and one that indicates the glacial origin of the rock. A tillite, therefore, is a more or less hard rock that was originally a till or glacial boulder-clay.

The area occupied by the Dwyka formation in Cape Colony can be divided into two distinct portions, the area lying south of latitude 33°, where there is a conformable succession from the base of the Cape system far into the Karroo system, and the area extending northwards from that parallel, in which the Dwyka rests unconformably upon the underlying rocks.

It is very probable that throughout the northern area the tillite reposes upon an undulating glaciated surface of older rocks, although exposures of such striated floors are not frequent. The reasons are that the Dwyka is usually much hidden under superficial deposits, and that the glaciated surfaces are rapidly destroyed through weathering once the cover of tillite has been stripped off. This is especially true of such rocks as granite, gneiss, and crystalline limestone, but on diabases, amygdaloids, and quartzites the striations are as a rule well preserved.

Striated floors below the tillite have been found at various places in Prieska and Hopetown, at Kimberley, along the Vaal River above its junction with the Orange, at Vryburg, in the Central and Eastern Transvaal, and in Natal and Zululand. The old floor undulates much, and through the cover of Dwyka there frequently project rounded polished and striated hummocks of rock with their longer axes usually approximately parallel to the striations crossing them. Frequently the ends directed one way are steeper, rougher, and not so deeply striated as the slopes facing the opposite way. These two sets of surfaces correspond exactly with the "crag and tail" or "lee and stoss sides" of the *roches moutonnées* that are met with in every region where ice has passed over hard rocks.

At Jackal's Water in Prieska the *roches moutonnées* formed by the quartzites of the Kaaien beds are very fine; they are shown in Plates X. and XI. The lee sides are on the south. At Vilet's Kuil in Hopetown the hard lavas of the Beer Vlei (Ventersdorp) volcanic group play a similar *rôle* to that of the quartzites of Jackal's Water, the lee sides being again on the south. In both of these cases the surface of the older rock retains the *roche moutonnée* form for a distance of some 200 feet from the outcrop of the Dwyka boulder-bed. Beyond this limit the rocks have lost their glaciated surfaces owing to weathering since the removal of the overlying tillite by denudation, but the characteristic outlines due to glacial erosion nevertheless remain.

Beautifully striated surfaces of Pniel lavas are found on the Vaal River near Pniel, Douglas and Riverton, to mention only a few of the important localities, and throughout this wide area the direction of the glacial striæ is generally from north-east to south-west with slight variations to the south or west.

In Gordonia the tillite is frequently seen between the Upington Commonage and Rietfontein, and it is the only rock other than superficial deposits met with in the few wells between the Hygap and the 22nd meridian;

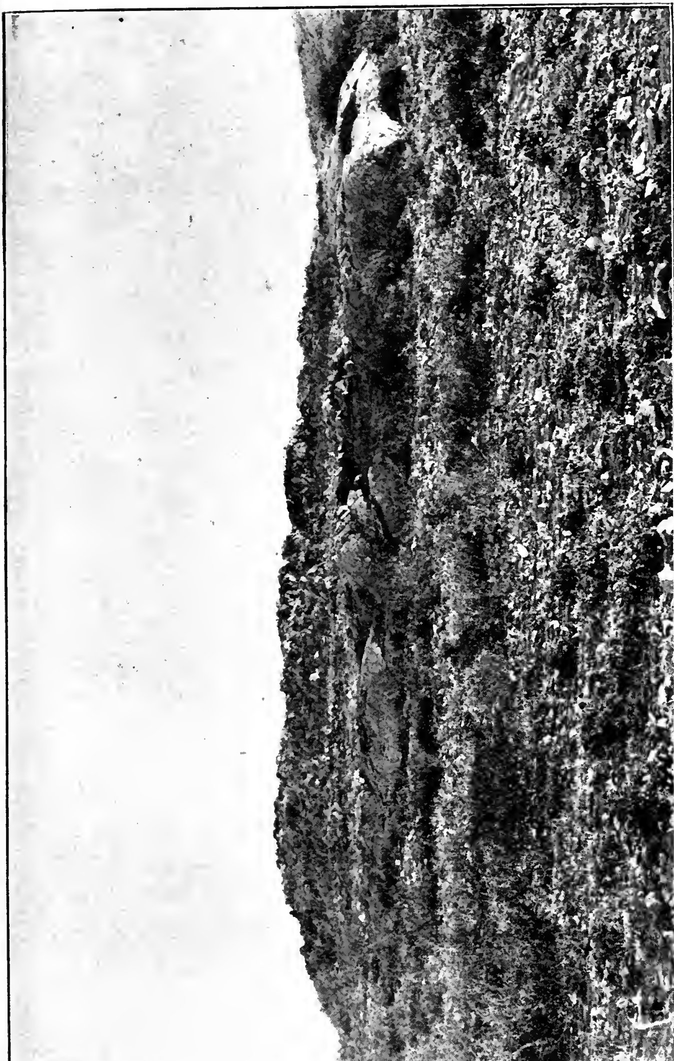


Plate X.—*Roches moutonnées* exposed by the removal of the Dwyka (in foreground) from the Kaaien quartzites at Jackal's Water, Prieska. The low hill behind the smooth surfaces is covered with angular quartzites broken from the Kaaien beds by the weather.

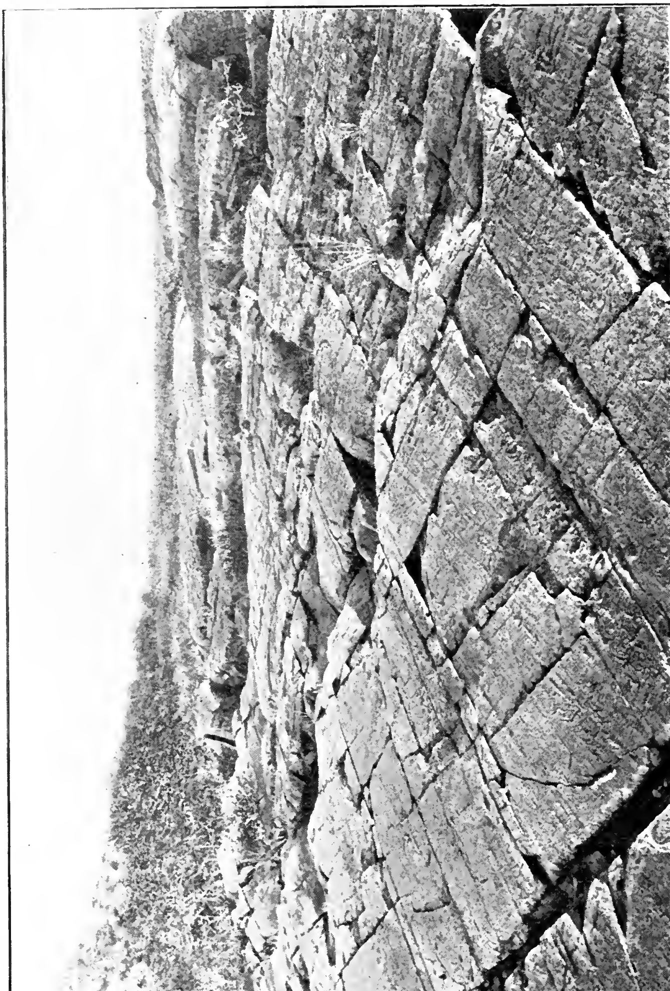


PLATE XI.—Near view of one of the glaciated surfaces at Jackal's Water, Prieska. The fine striations passing obliquely across the surface and cutting the bedding-planes are the glacial scratches. The bed-planes cause the cracks stretching from the left edge to the bottom of the picture.

it is again seen filling old valleys cut out of the Matsap series near Kuis on the Molopo. These exposures indicate the existence of an outlier, perhaps over 10,000 square miles in area, north of the Orange River and west of the Korannabergen. The outlier is continued in German South-West Africa and in the Bechuanaland Protectorate. Though the base of the tillite has been seen at several spots where it rests upon granite and shales and sandstones of the Zwart Modder series, a striated floor has not been found, doubtless owing to the nature of the older rock, which is not favourable for the retention of striæ. Between Van Wyk's Vlei (Carnarvon) and the Langberg (Calvinia), a distance of 150 miles, the boundary of the Dwyka has not been traced. In Bushmanland the tillite rests upon granite and gneiss (Plate XII.), and farther south upon the Ibiquas beds without being in the least affected by the great dislocation which separates the granite from the latter. South and west of Uithoek the much-denuded Table Mountain sandstone intervenes between the Ibiquas and the Dwyka, and higher and higher beds are seen to the south; south of the Oorlog's Kloof River the Bokkeveld beds appear. Fifty miles farther south the Dwyka rests upon the basal beds of the Witteberg series, and the latter formation continually thickens as Karroo Poort is approached. At only two or three spots along this part of the boundary has the actual contact been seen, and although the surface of the Witteberg quartzites is striated at those places there are so many slickensided surfaces in the same rocks, produced by the bending and consequent slipping of one layer over

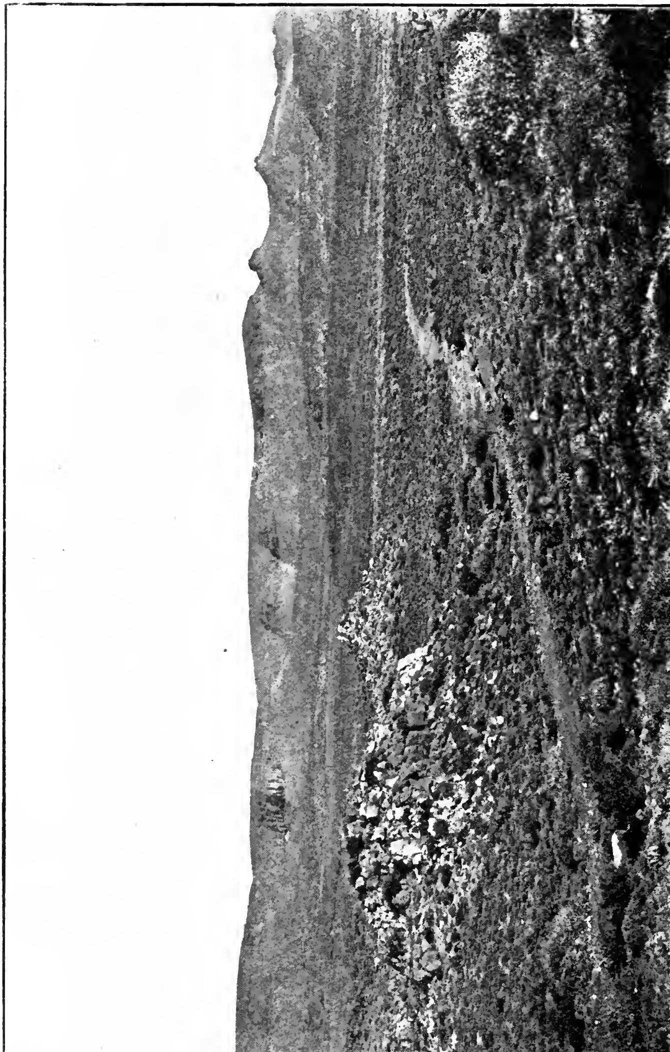


Plate XII.—Escarpment of the Dwyka tillite near Ibiquas River, Calvinia. The rock in the foreground is the Bushmanland granite.

another during the folding of the rocks, that in the absence of favourable exposures it is impossible to be certain of the glacial origin of the scratches immediately below the boulder-bed.

At Eland's Vlei, near the confluence of the Tanqua and Doorn (Clanwilliam) Rivers there is exposed a "striated pavement" not of the underlying rock, but of the tillite itself, which passes under a further thickness of boulder-bearing material. The pavement is a flat surface of tillite in which there are numerous boulders up to three feet in diameter pressed down flush with the surface of the pavement. These boulders are finely striated in a direction which is almost due east; such striæ as they may have running in other directions have been largely obliterated by the agency which produced those mentioned. The matrix of the tillite, a tough blue sandy mudstone, is traversed by numerous furrows running parallel to the dominant striæ on the boulders. There can be little doubt that this surface, which is from fifty to eighty feet above the base of the boulder-bed, was produced by ice moving across it. After the ploughing up of the glacial material the ice disappeared and a sandy mud with boulders and pebbles, precisely like the tillite below, was deposited upon the "pavement".

A similar example has been found in the Vaal River Valley a few miles north-west of Riverton, the direction of the striation and furrows being from north-east to south-west. Many instances of such surfaces occur in recently glaciated regions; they are produced whenever a glacier or large sheet of ice moves over a floor of boulder-clay or till.

A short distance north of Karroo Poort shales make their appearance between the tillite and the quartzites of the Witteberg series ; southwards and eastwards they rapidly become thicker. They consist of greenish and bluish shales and thin quartzitic sandstones and are in all from 400 to 1,400 feet thick, measured from the uppermost thick quartzite of the Witteberg group to the lowest bed that is distinctly pebbly. Some of the strata are very like the shales of the Witteberg, and others, especially near the top, are of the same nature as the matrix of the tillite. Although they are undoubtedly passage beds between the two formations, they are placed for convenience with the boulder-beds and are called the Lower Dwyka shales. On the Witteberg River the shales have been found to contain impressions like the *Phyllotheca* stems of the Ecca beds; fossil stems have also been found in the Lower shales near Zoetendal's Vlei in Willowmore.[1]

The Lower Dwyka shales are well exposed at many places along the north flank of the hills formed by the Witteberg series along the Southern Karroo, *e.g.*, near Matjesfontein, in the Witteberg's River south of Laingsburg, at the north end of the Buffel's River Poort (Leeuw Kloof Poort), south of Prince Albert, and in Willowmore. In the neighbourhood of Kando's Poort and at Zoetendal's Vlei the Lower shales are over 1,350 feet thick. At Grahamstown, both to the north and south of the town, similar shales 650 feet thick intervene between

[1] Schwarz, *G. C.*, viii., p. 94.

the Witteberg quartzites and the Dwyka boulder-bed, lying conformably to both. There can be hardly any doubt, therefore, that the lower shales are a definite group of beds present at the base of the Dwyka series wherever it lies conformably upon the Witteberg beds.[1]

It seems probable that the Southern Dwyka, which is thicker and more uniform in character over wide areas than that in the north, represents the silt and boulders carried southwards by water and floating ice and deposited in water. It includes some thick bands of shales with few pebbles and boulders, traceable for considerable distances. The Northern deposits are, on the other hand, extremely variable both in their nature and thickness, but generally speaking show two fairly distinct phases. In one of these the tillite forms a bed seldom more than thirty feet in thickness and is succeeded rather abruptly by soft shales. In the other the deposit is much thicker and more or less regularly bedded, consisting of alternations of conglomerate and shaly material, shale, and sometimes limestone, while the shales above may enclose occasional boulders.

The second type is especially characteristic of the valley of the Harts River and the portion of the Vaal Valley that forms its south-westerly extension; it fills a wide depression which existed as a valley in Pre-Dwyka times and which is now in process of re-excavation. This type of deposit is most probably in great part or wholly of fluvio-glacial origin, thus resembling the southern Dwyka, while the first type may well have been formed on land or in very shallow water at the end of glaciers

[1] Schwarz, *G. C.*, viii., pp. 88, 89.

or an ice sheet. The shales must have been deposited in quiet water in which the boulders dropped to the bottom from floating ice.

The northern boulder-beds frequently include bands in which large boulders are very numerous, but in the south such occurrences are rare. In the Tanqua Karroo a fairly constant band of large boulders stretches for many miles north and south of Eland's Vlei. It is about fifteen feet thick and some of the boulders are from three to four feet in diameter, though most of them are less than half this size. Another definite boulder-band has been found in the valley of the Witteberg's River south of Laingsburg, and is shown on Plate XIII. The largest block seen in the photograph is ten feet across.

Along a line extending from Modder River Station south-westwards to the Orange River the normal type of Dwyka is replaced by soft sandstone, which is calcareous in places and encloses occasional small boulders.

The tillite of Calvinia is very much like that of Prieska, being fairly soft and sometimes shaly. In the Tanqua Karroo it is slightly harder, while a little north of Karroo Poort it becomes more indurated as the result of earth-movement.

Throughout the southern outcrops the tillite is a hard blue rock from which the pebbles cannot easily be broken; when the rock is struck with a hammer the fracture is more likely to pass through a pebble than round it, while the northern rock breaks up readily and the pebbles can easily be removed from the matrix.

There is a rough cleavage developed in the southern rock, parallel to the strike of the beds, but at various

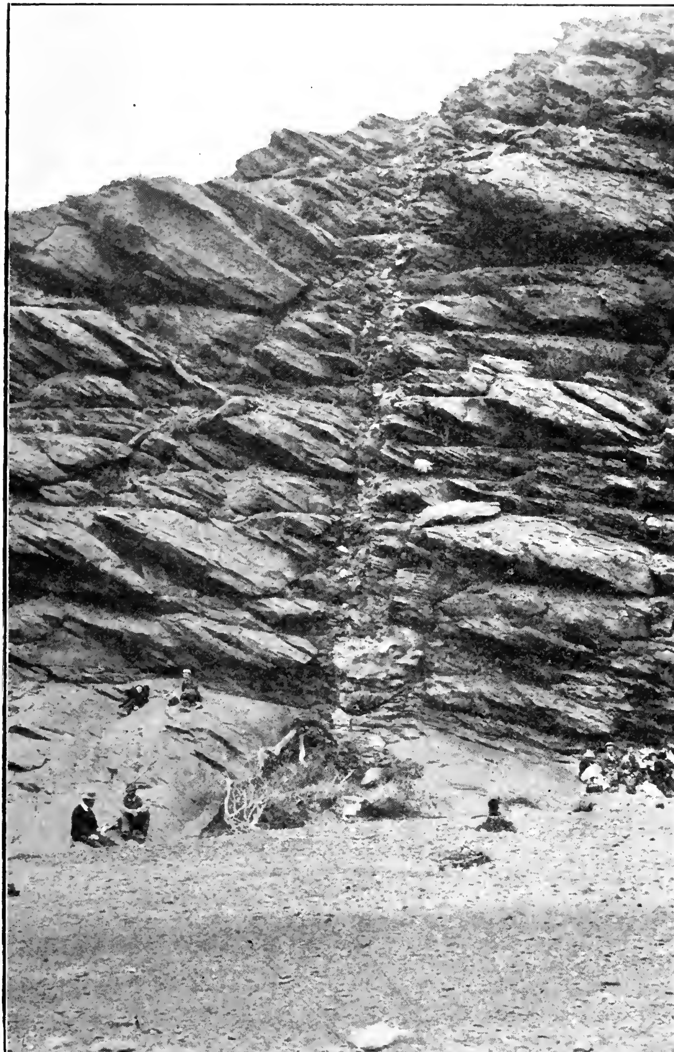


Plate XIII.—Dwyka tillite with a band of boulders, Witteberg's River, Laingsburg. The largest boulder, near the base of the cliffs, is 10 feet in diameter. The almost horizontal lines are joints; the inclined planes dipping south, from left to right, are due to cleavage.

angles to their dip. This causes the tillite to weather into lenticular slabs, which are very characteristic of the outcrops in the southern parts of the Colony. This slab or "tombstone" structure, as the late Prof. Green called it, is shown on Plate XIII. In the Karroo outside Karroo Poort, where the Dwyka tillite has been affected by the pressures that produced the east and west folds (Zwartberg folds) and also by those which gave rise to the north and south folds (Cederberg folds), the rock has the rough cleavage developed in two directions and weathers out into pillars, usually tapering upwards. The development of the slab-structure becomes weaker as the formation is followed northwards into the region where folding did not take place.

A curious feature in both the northern and southern boulder-beds, but more highly developed in the latter, is the regular and close jointing of the inclusions. A pebble only a few inches long may be traversed by a dozen or more joints parallel to one another, and quite independent of the original divisional planes, such as those of bedding or foliation, in the pebble. In the north and north-west where the boulder-bed lies nearly horizontally, the joints are also horizontal, but occasionally vertical ones can be found.[1] In the south the joints, which are parallel in all the pebbles at any one spot, lie more or less parallel with the strike, but not with the bedding planes in the boulder-bed. Occasionally one or more of the sections into which the pebbles are divided have been shifted relatively to the others; the matrix of the rock shows no sign of the continuation of the joints through it.

[1] See Plate V., *T. S. A. P. S.*, vol. xiv., p. 402, 1903.

At several places in the west and south of the Karroo thin beds and thick lenticular masses of white quartzite occur in the tillite. Near Matjesfontein Station several large lenticles of quartzite lie on one horizon; they are roughly bedded and their dip is the same as that of the enclosing tillite. In the Ceres Karroo near Beukes Fontein, there are also several quartzite lenticles like those at Matjesfontein, but the quartzite is gritty and yellowish in colour, and at its periphery contains boulders. These lenticles are very probably analogous to the interbedded deposits of sands and gravels in the till of the northern hemisphere.

Some patches of the tillite contain more carbonate of lime than the rest of the rock, and they weather out in the form of spheroidal and lens-shaped lumps that occasionally pass into masses large enough to be called lenticular beds. The spheroidal lumps are usually from six to ten inches in diameter and seem to be particularly abundant near Laingsburg and in the Tanqua Karroo, but they have been found in Gordonia and many other districts. The carbonate of lime in these concretions has probably reached its present position by a slow process of concentration from the surrounding rock, which always contains a certain amount of calcite.

In the Harts-Vaal Valley and in Gordonia beds of limestone up to eighteen inches in thickness are not uncommonly interbedded with the glacial deposits.

Another peculiar variety of deposit is known as *gravel Dwyka.* It is composed of small fragments of rock, more or less irregular in outline, cemented by a small proportion of sandy calcareous material and is intensely hard. The inclusions are seldom glaciated.

Where the Dwyka first appears on the coast of Pondoland, near St. John's, it is faulted down against the Table Mountain beds that form the mountain through which the St. John's River flows just before reaching the sea. To the north-east of St. John's, along the western flank of the high plateau of Table Mountain sandstone that borders the coast, the tillite rests directly upon the sandstone; no part of the Bokkeveld or Witteberg series has been left between the two formations, which stand in the same relation to one another as in Calvinia, north of the Oorlog's Kloof River. In Natal the tillite rests upon an uneven surface of the Table Mountain sandstone and Pre-Cape rocks. The rock in Pondoland has precisely the same general appearance as in Calvinia and the Western Karroo, but there is not quite the same assemblage of rocks among the boulders.

A considerable amount of information regarding the source and movements of the glaciers or ice-sheet which produced the glacial deposits can be gathered from the direction of the striæ on the *roches moutonnées* and from the characters of the various boulders found in the tillite.

From Vryburg to beyond Prieska the general direction of movement appears to have been towards the south-west, but there was a marked deviation to the south and even a little east of south in the neighbourhood of Beer Vlei as well as many minor local deflections. The inferred course of the ice-sheet is indicated in Fig. 12.

Between Van Wyk's Vlei and Calvinia the direction of the movement is not known, but the "striated-pavement" at Eland's Vlei in the Tanqua Karroo indicates a flow of ice from the west.

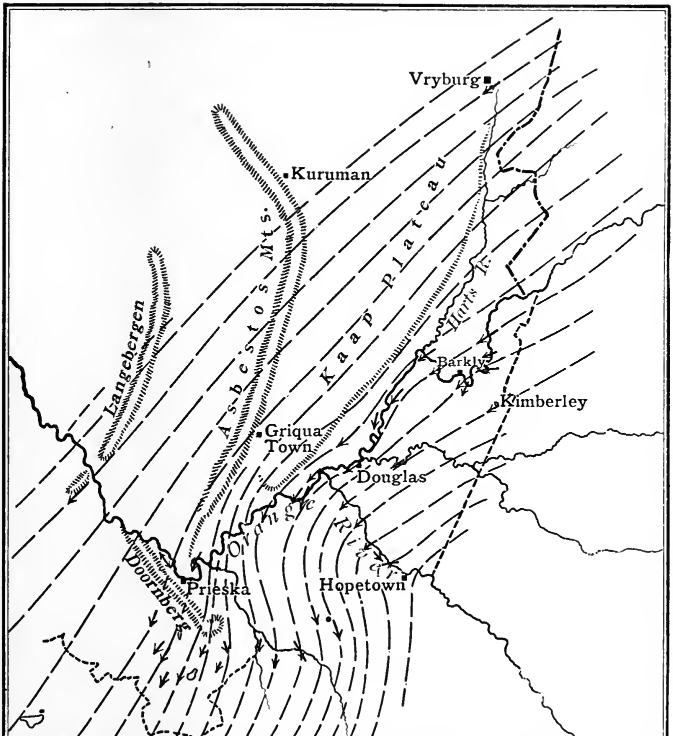


Fig. 12.—Map showing the direction of the Ice-movement during the Dwyka glaciation. The arrows mark the positions of observed glaciated surfaces.

In Natal the glaciated surfaces indicate a movement from the north-north-west and the same is the case in the Central and Eastern Transvaal. The ice sheet appears therefore to have spread outwards from a centre either in the Northern Transvaal or in Rhodesia.

The boulders in the tillite of the Transvaal and of Natal confirm the evidence afforded by the glacial striæ, for the majority of the inclusions can be matched with rocks found *in situ* in the Central Transvaal. In Pondoland, while various kinds of granites, gneisses, diabases, quartzites, etc., are abundant as boulders, the jaspers and banded ironstones of the Griqua Town series, which form a small but interesting part of the inclusions in the west and south of the Karroo, are unrepresented.

In Griqualand West the majority of the boulders are diabases and amygdaloids from the Ventersdorp system, a formation which covers an immense area in the South-Western Transvaal. With them are quartz-porphyries like those at Klerksdorp, and red granite identical with that of the Bushveld. Wherever the ice has passed over and glaciated an outcrop of a rock with easily recognisable characters the tillite immediately to the south-west contains abundant inclusions of the rock in question. Thus at Delport's Hope the Dwyka is full of angular and partially rounded masses of Black Reef quartzite derived from an outcrop a little to the north. For miles to the south-west of Klokfontein, near Modder River, boulders of rhyolite from that locality are recognisable in the tillite. South-west of the Doornberg in Prieska boulders from the Griqua Town beds are abundant, while near Van Wyk's Vlei inclusions from the Matsap beds first make their appearance.

Serpentines, found in the tillite west of Calvinia, are as yet only known in place in the north of the Colony. In the Tanqua Karroo quartzites and sandstones of various kinds predominate; some may have come from the Table Mountain and Bokkeveld series north of the unconformity. Along the west and south of the Karroo the boulder-bed contains numerous inclusions of microcline-granites like those of Northern Cape Colony, quartzites and quartz-schists from the Kheis series, diabase and amygdaloids like those of the Ventersdorp system, cherts, limestones, and dolomites from the Campbell Rand series, banded jaspers and ironstones from the Griqua Town series, and purple quartzites, grits, and conglomerates from the Matsap beds.

The bulk of the formations that have supplied the boulders of recognisable origin are only known in the north; there is no clear evidence that any of them had a southern origin, and so far as is known the Dwyka was laid down conformably to the Cape formation throughout the south of the Colony.

The boulder-beds are about 1,000 feet thick in the south of the Karroo, but the thickness diminishes northwards. Where it lies nearly horizontally, as in the north of the Colony, it covers wide stretches of country, but is of varying thickness though never more than a few hundred feet.

In Griqualand West the tillite was deposited upon a very uneven surface, and the variation in level of the old floor is often very considerable; a change of altitude of as much as 800 feet is known to occur within a distance of a few miles. The glacial deposits are in consequence much thicker in the depressions than over the ridges, and in not a few cases the tillite is completely absent on the latter. The same variations of level of the old floor and consequent change in thickness of the tillite from point to point are well marked in the Transvaal and in Natal.

Lying above the boulder-beds in the south and west there are some 500 to 600 feet of sediments called the Upper Dwyka shales, into which the tillite passes conformably by the gradual diminution in the number and size of the boulders. The lowest beds are bluish or greenish sandy shales, overlain by thin sandstones, which are in turn succeeded by a group of black shales weathering white on exposure to the air. The black shales are followed by fine-grained green beds with thin beds of limestone and ferruginous rocks, and several layers of chert, grey or black when freshly broken, but with a thin white crust on exposed surfaces. The uppermost of the chert beds, usually from eight to twelve inches thick, is taken as the top of the Dwyka series. The black shales contain a certain amount of carbonate of lime often gathered together in the form of nodules, and iron pyrites. These two minerals and the carbonaceous matter, that gives the black colour to the shales, decompose under the influence of the air, forming gypsum (sulphate of lime) and iron oxides, leaving the shales white. These white rocks make very conspicuous features on the southern, western, and northern borders of the Karroo, where the vegetation is not sufficiently abundant to hide the colour of the bare hill-sides. Thus the black shales near the top of the Dwyka series are known as the "White band".

The dark colour of these shales has led to their being prospected for coal at many places, but although the percentage of carbonaceous matter rises to 12 per cent. inclusive of some volatile hydrocarbons, nothing that can fairly be called coal has been found in them in Cape Colony. On the banks of the Camdini River near Loeries Fontein the black shales are very well exposed, and they are traversed by dykes of dolerite, which have brought about the formation of graphite in minute scales, filling cracks in the immediate vicinity of the igneous rock.

The Upper Dwyka shales change slightly in character in the north of the Colony; they cover wide areas in Prieska, Carnarvon, Hopetown, Britstown, and Griqua land West, where they have been called the "Kimberley shales". They have a thickness of from 250 to 500 feet, and at the top are found the white-weathering black shales corresponding to the "White band". The chert band is absent, but the ferruginous layers and limeston s are represented; their thickness, including some ordinary shales, ranges from 25 to 50 feet or perhaps more. In Gordonia there are shales with a small amount of carbonaceous matter above the tillite, but no definite limit between these shales and what are possibly Ecca beds has been recognised.

The distribution of the Dwyka series can be seen at a glance on the geological map of the Colony. The boulder-beds are probably almost everywhere present at the base of the Karroo system, and south of the Orange River they have a persistent though varying dip towards the interior, so that they form a basin. On the east, south, and west the form of the basin is due to folding, but the gentle inclination of the northern portion may be partly or wholly an original feature.

The outliers of the Dwyka series in the folded belt south of the Karroo are few in number. The chief one is that which forms a semicircular area between Worcester and Lange Vlei near Robertson on the downthrown side of the great Worcester fault.[1] The rocks are of precisely the same general character as those along the south of the Karroo, but the black shales have in places been converted into graphitic slates. In the Worcester district, as in the Karroo, the boulder-beds rest upon the lower shales, and these again lie conformably upon the Witteberg beds. The Worcester outlier is about forty miles distant from the nearest part of the main Dwyka area in the Karroo, and is particularly interesting because it shows no sign of a change in the nature of the beds or in the relationship between them and the older rocks. In the small outlier at Robertson, however, the lower shales are much thinner than usual. With this exception these facts, together with the uniform character of the conglomerate and its mode of occurrence, at least as far east as Grahamstown, warrant the assumption that the area of deposition of the Dwyka series was not limited in a southerly direction within the boundaries of the Colony.

Outliers of Dwyka have also been found at the head

[1] Schwarz, *G. C.*, i., p. 27.

of the Winkelhaak River in the Cold Bokkeveld, at Quarrie Kloof between Touw's River and Constable stations, and at four other places in that neighbourhood. One of them is in Dobbel Aar's Kloof, about thirty miles south of the Quarrie Kloof outlier. All these outliers are boat-shaped synclines, with the exception of the first, which is bounded on one side by a fault.

Between Karroo Poort and Grahamstown the outcrops of the Dwyka are repeated by folding, but their distribution east of Steytlerville is not known in detail.

The question of the presence of coal in the Dwyka shales beneath the Karroo is one that must be briefly touched upon. Mr. Dunn in 1886 [1] came to the conclusion that the carbonaceous shales of the White band would contain coal at certain points in the Karroo where they are hidden by a great thickness of Ecca and Beaufort beds. In 1899,[2] when he found that the Vereeniging coal rested upon the Dwyka conglomerate, he naturally considered his case for the existence of sub-Karroo coal greatly strengthened. The facts, however, are that the black shales taken at various points along an outcrop of about 1,000 miles round the edge of the present basin of the Karroo show remarkably uniform characters and that their carbon content is invariably low. Mr. Dunn supposed that the vegetable material would be swept in towards the centre of the basin and that the shale would be replaced by coal as the centre

[1] Dunn, E. J., "Report on a Supposed Extensive Deposit of Coal Underlying the Central Districts of the Colony," Parl. Rep., G. 8, Cape Town, 1886.

[2] Dunn, E. J., "Notes on the Dwyka Coal-Measures at Vereeniging, Transvaal," *T. S. A. P. S.*, xi., p. 67, 1900.

was approached. To this view is opposed the fact that the edge of the present basin is by no means coincident with the original limit of the Dwyka; for, as already remarked, the beds must have at one time extended much farther to the south, while in Gordonia there is an outlier of immense size far away from the main outcrop. Again, recent work has cast suspicion on the view held by Dunn, and also by Hatch and Corstorphine,[1] that the Vereeniging coals belong to the Dwyka series, and it may ultimately prove that, as held by Molengraaff[2] and Mellor,[3] the Transvaal coal is of somewhat later age. Even supposing for the sake of argument that coal did exist below the Karroo, the possibility of mining it would be very remote. In the Southern Karroo the depth at which the top of the Dwyka would be reached near Beaufort West must be some thousands of feet. In the Northern Karroo it is found that great sheets of dolerite have been intruded in the sedimentary rocks along the horizon of the White band or on one a little above or below it, a circumstance that is unfavourable to the retention of useful properties by coal beds, should they exist there.

Fossils are scarce in this formation. A few specimens of the small reptile *Mesosaurus* have been found in the Kimberley Mine, in Herbert, Southern Bushmanland,

[1] Corstorphine, G. S., "The Age of the Central South African Coal-field," *T. G. S. S. A.*, vi., p. 16. Hatch and Corstorphine, *The Geology of South Africa*, 1905, pt. ii., ch. 1.

[2] Molengraaff, G. A. F., *The Geology of the Transvaal*, Edinburgh and Johannesburg, 1904, p. 75, etc.

[3] Mellor, E. T., "The Position of the Transvaal Coal-Measures in the Karroo Sequence," *T. G. S. S. A.*, ix., p. 97.

and Calvinia, as impressions left in the shale of the White band by the removal of the animal's bones. Well-preserved fish remains have also been obtained from this horizon in Calvinia. The list of fossils is as follows :—

Upper Shales:
- Plants—
  - *Lepidodendron australe*,[1] McCoy.
- Reptilia—
  - *Mesosaurus tenuidens*,[2] Gervais.
  - *M. pleurogaster*,[3] Seeley.
  - *M. capensis*,[4] Gürich.
- Crustacea—
  - Probably *Anthrapalæmon*, sp.
- Fishes—
  - *Elonichthys*, sp.

Tillite—
  - *Gangamopteris*, sp.[5]

Lower Shales—
  - *Phyllotheca*, sp.

2. The Ecca Series.

Lying conformably upon the Upper Dwyka shales throughout Cape Colony is the group of shales and sandstones called the Ecca beds, a name given them by Atherstone from their occurrence in the Ecca Pass north of Grahamstown. It is worth while noting here that the term has been employed in a somewhat different sense by certain geologists in the Transvaal and

[1] A. C. Seward, *G. M.*, p. 484, 1907.

[2] P. Gervais, *Description du Mesosaurus tenuidens*, Montpellier, 1865.

[3] H. Seeley, *Q. J. G. S.*, p. 586, 1892.

[4] R. Broom, *T. S. A. P. S.*, xv., p. 103, 1904 ; *A. S. A. M.*, iv., pt. 8, 1908.

[5] *G. C.*, xii., p. 182.

Natal, who include in the Ecca beds the strata that immediately succeed the Dwyka tillite.

Attention has already been drawn to the uncertainty as to the exact geological horizon of these beds, and in our present state of knowledge it would be useless to discuss the question of correlation any further. Throughout Cape Colony, however (except near Rietfontein in Gordonia), where the Karroo formation appears to have been more fully developed than in the neighbouring Colonies, the name Ecca series has for various reasons been applied by the Geological Survey to the beds that overlie the "White band" of the Dwyka series or the highest chert band in that formation when beds of chert are present.

In the south and west of Cape Colony the lowest Ecca beds are usually thin flaky blue shales, and green shales are found above them, together with thin beds of mottled grey and green sandstone. Some of the shales near the base of the series break up into long roughly prismatic fragments after the manner of the starch of commerce. In the neighbourhood of Patata's River south of the Klein Roggeveld hard sandy beds lie immediately above the Dwyka series. The thickness of the lower portion of the Ecca beds in the south and west, in which the shales predominate, is from 1,000 to 1,200 feet, and they are succeeded by some 1,200 feet of strata in which sandstones are the chief feature. These, called the Laingsburg beds from their occurrence near the town of that name, are hard, dark-coloured, fine-grained sandstones and hard shales; they contain *Glossopteris*, *Schizoneura*, *Phyllotheca* and silicified wood. On the weathered surface the sandstones are usually yellowish, but some of the finer-grained beds break up into rounded fragments with a thin red crust. The Laingsburg beds have been traced through the country on the south and west of the Klein Roggeveld, where they form very hilly ground, and at Schoorsten Berg over 2,500 feet of strata are exposed belonging to the lower and middle divisions alone. In the Tanqua Valley the sandstones become much thinner and disappear, being perhaps represented by shales farther north.

The uppermost portion of the Ecca beds in the Southern and Western Karroo varies considerably in the proportions of sandstones and shales in different localities. The sandstones are frequently mottled grey and blue. On the Kraai River, near Tuin Plaats, *Glossopteris*, *Gangamopteris*, and *Schizoneura* occur in hard shales belonging to these beds.

In the Roggeveld and Hantam region the sandstones that are so conspicuous in the country farther south are but slightly developed, and the whole of the Ecca series becomes an essentially argillaceous group, with only thin beds of sandstone intercalated with the shales; calcareous concretions in the latter now become abundant. The thickness of the series diminishes in the same direction, and is probably somewhat over 2,000 feet near Calvinia village. The rocks are well exposed on the Hantam Mountains and on the Roggeveld escarpment, of which the former were once a part, having been detached from the main mass by the erosion due to the Oorlog's Kloof River.

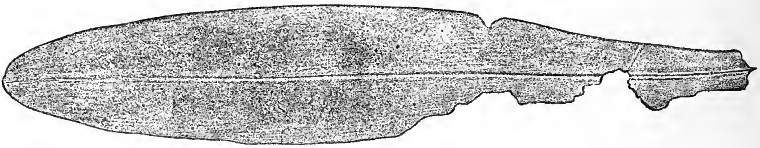
Between the Hantam and Van Wyk's Vlei nothing is known about the Ecca beds, but the formation from the latter point onwards is markedly argillaceous, and as far as the Orange River it forms a wide belt showing great lithological uniformity. Sandstones are practically unrepresented, and the beds are almost entirely bluish and greenish shales, which, towards the summit of the formation, become rather flaggy. Calcareous concretions are very abundant, more especially in the middle portion of the series. No recognisable plant remains have been obtained in this northern area, though the shales are frequently crowded with indistinct fucoid-like markings. Silicified wood is present, but it is not abundant. The strata along the north of the Karroo have a constant though very low dip towards the south, and the formation must have a thickness of about 2,500 feet. A small outlier of Ecca beds builds up Kols Kop a little to the north of Belmont.

In Willowmore the normal phase of the southern Ecca is replaced by shales and sandstones exhibiting a white spotting or mottling on a blue or greenish-grey background. They contain a large amount of silicified wood, and some limestone; the latter is penetrated by thin veins of chert. The area occupied by this "mottled Ecca" is as yet unknown.

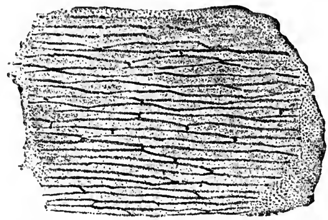
In Pondoland the Umsikaba beds occur just above the black shales of the Dwyka series. They are of considerable but unknown thickness, and differ in character from the typical Ecca beds of the west; they consist more of clays and mudstones than of shales and sandstones. Near their base, as seen on the road to Lusikisiki from St. John's and near the Embotyi mouth, they are better laminated than higher up in the group; the surfaces of the laminæ are frequently spotted with circular rusty markings about the size of a shilling, perhaps due to the decomposition of iron pyrites distributed more or less uniformly through them. Above these shales come the clays and mudstones, occasionally sandy, dark blue in colour. On the south of the St. John's fault, along which the Dwyka and Ecca beds are let down against the Table Mountain sandstone, the Umsikaba beds are harder and more like the Ecca of the west than in other parts of Pondoland. At Cape Hermes some thin shales contain obscure plant remains reminding one of the *Schizoneura* stems of the west. The Umsikaba beds are found from Libode to Bizana, but have not been followed south-west of Libode.

In the Worcester District the Ecca beds are faulted down against the Pre-Cape rocks between a point some four miles west of the town of Worcester and the Goree River, and again near Robertson. The beds are green and brown argillaceous sandstones and shales and mudstones, sometimes coloured green and red. From the sandstones and mudstones exposed in a small quarry near Worcester station specimens of *Gangamopteris*, *Glossopteris*, and *Cardiocarpus* have been found; the last-named genus is not known elsewhere in the Colony, although it occurs at Vereeniging; *Schizoneura* occurs in a quarry west of Worcester.

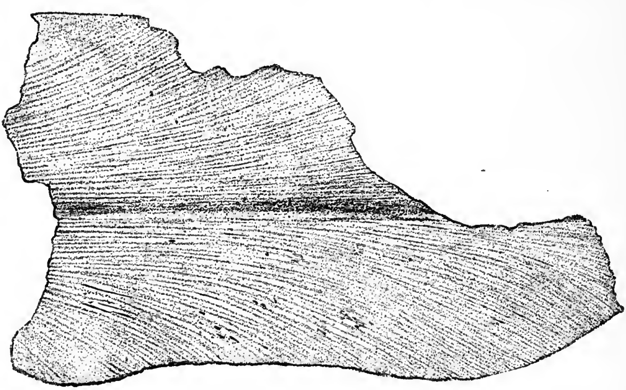
The list of fossils from the Ecca beds in the Colony is short, and with the exception of a portion of a reptilian skull, *Archæosuchus*, and a humerus, *Eccasaurus*,[1] from the Prince Albert District, contains the names of plants



Glossopteris browniana, var. *indica*. Half natural size.



Glossopteris browniana, var. *indica*. A portion of a leaf, magnified.



Gangamopteris cyclopteroides. Natural size.

FIG. 13.—Plants from the Ecca beds (from Seward).

alone. Their number is augmented if we include the

[1] Broom, *Rec. Albany Museum*, vol. i., p. 341, 1905; *A. S. A. M.*, vii., pt. 3, 1909.

forms obtained by Mr. Leslie from Vereeniging and described by Prof. Seward,[1] assuming provisionally that the strata there are of Ecca age.

CAPE COLONY.

Schizoneura, sp.
Phyllotheca, sp.
Cardiocarpus, sp.
Glossopteris browniana, Brongt.
Gangamopteris cyclopteroides var. *attenuata*, Feistm.
Cordaïtes (*Noeggerathiopsis*) *hislopi*, Bunb.

Reptilia—
Archæosuchus cairncrossi, Broom.
Eccasaurus priscus, Broom.

Fish scales—

VEREENIGING.

Schizoneura, sp.
Cardiocarpus, sp.
Conites, sp.
Glossopteris browniana, *G. angustifolia*, *G. indica*, *G.* cf. *retifera*.
Gangamopteris cyclopteroides, Feistm.
Sphenopteris, sp.
Psygmophyllum kidstoni, Sew.
Sigillaria brardi, Brongt.
Bothrodendron leslii, Sew.
Callipteridium?
Neuropteridium validum, Feistm.
Cordaites (*Noeggerathiopsis*) *hislopi*, Bunb.
Lepidodendron pedroanum, Carr.
L. vereenigingense, Sew.

3. THE BEAUFORT SERIES.

The Beaufort beds take their name from their occurrence in the Beaufort West and the Fort Beaufort

[1] Seward, *Q. J. G. S.*, p. 52, 1898; *A. S. A. M.*, vol. iv., pt. i., 1903; *Q. J. G. S.*, p. 109, 1908.

Divisions; they consist of sandstones, shales, and mudstones.

The sandstones are usually light yellow in colour and are of two kinds, a rather loose-grained rock that forms thick bands of strata in the Nieuweveld area and the Midlands, often giving rise to plateaux and terraced features, and a finer grained rock which is in thinner beds and which usually weathers in rounded lumps with a red or brown crust. The first variety is called "defining sandstone,"[1] and the second "intermediate sandstone," for owing to the difference in the weather-resisting qualities of the two rocks the thick sandstones cap the larger terraces, while the intermediate sandstones make smaller ledges on the mountain sides. The sandstones are often false-bedded and may have their surfaces ripple-marked.

The shales and mudstones are usually dark blue or greenish, but are sometimes deep red and purple in colour; they are commonly less fissile than those in the Dwyka and Ecca series. Concretionary nodules and lenticular layers of brown weathering blue-black limestone are abundant, as in the Ecca, but often contain small veins and pipe-like rods of pink or white chalcedony. From the fact that both the limestone and chalcedony often permeate the bones of fossil reptiles they seem to have been closely connected in their origin with the presence of organic matter. These nodules weather out of the shales in great numbers and can be seen along the railway between Groot Fontein and Beaufort West.

[1] *G. C.*, i., p. 15.

Beds of "clay-pellet conglomerate" are often seen at the base of the sandstone beds; it is a rock with a mudstone or sandstone matrix containing numerous rounded or flattened lumps of mud, rather different in colour from the matrix and finer grained. The lumps of mud were derived from previously deposited sediment, and were rolled along by the current till they came to rest where they are found. The tidal lagoons of the Eastern Province rivers and the lower part of the Olifant's River (Van Rhyn's Dorp) are good places for the observation of the formation of mud-pellets on a muddy or sandy bottom, while the Orange River near Prieska has many sandy stretches along its banks exposed during dry seasons and covered with mud-pellets brought down by the last flood. There is no doubt that mud flats exposed at the surface of shallow water would furnish lumps of mud to the small waves washing the margin, and it is probable that the clay-pellet conglomerates in the Karroo formation were formed in this way.

Local unconformities affecting the beds over small areas, sometimes only a few yards wide, are very abundant in the Beaufort and Ecca beds. The lower-lying strata are cut off by the upper to the depth of, perhaps, four or five feet, usually less, and the higher beds thicken out to occupy the depression made in the lower. These hollows are usually in shales or mudstone, and the rocks filling the hollows are sandstones or clay-pellet conglomerates. The frequency of these examples of "contemporaneous erosion and deposit" point to the deposition of the strata in quite shallow water which from time to time received sudden accessions from rain floods, or possibly also had strong streams developed in it by a constant wind.

The clay-pellet conglomerates in the Beaufort series frequently contain rolled pieces of bone. Pebbles of rock are very rare both in the conglomerates and the other strata, and the few that have been found do not reach a length of two inches.

Coal has been found in thin layers in the Beaufort beds (see p. 463).

As this formation comprises a thickness of several thousand feet of rock and covers a vast area, attempts have been made to subdivide it into smaller groups on either lithological or palæontological grounds. So far it has been found possible, by means of the various reptilian genera, to divide the formation into three groups,[1] each of which can be subdivided into zones:—

Upper Beaufort	6 *Cynognathus* beds
	5 *Procolophon* ,,
Middle Beaufort	4 *Lystrosaurus* ,,
Lower Beaufort	3 *Kistecephalus* ,,
	2 *Endothiodon* ,,
	1 *Pareiasaurus* ,,

Since the reptilian remains are either scarce or absent over wide areas it is obviously very difficult to determine the limits of these zones in the field, and on the other hand, owing to the small area yet mapped, it is not quite known how far a lithological subdivision is possible throughout the Colony, or whether such lithological zones would, if traced out, coincide with those based on the distribution of the fossils.

[1] R. Broom, papers read at the joint meeting of the B. and S. A. A. A. S., 1905, vol. ii., p. 38; *G. M.*, 1906, p. 29.

The Lower Beaufort Beds.—In the Northern Karroo, in Philipstown, Victoria West, and Carnarvon the blue flaggy shales of the Ecca are followed by massive yellow weathering sandstones; this change from an argillaceous to an arenaceous formation is quite abrupt. The base of the sandstones has been taken to mark the base of the Beaufort series, and this divisional line is also found to hold good near Calvinia and in the Roggeveld (Fish River Valley). South of the Roggeveld the Ecca beds become more arenaceous, but the approximate junction has been traced round the Klein Roggeveld, and through the Moordenaar's Karroo and Gouph, while in Prince Albert the base of the Beaufort has been taken at the lowest stratum containing the remains of *Pareiasaurus*. The exact limits of the formation east of Prince Albert is not known. Near Aberdeen A. H. Green[1] described an apparent unconformity which may possibly be at the base of the Beaufort, while

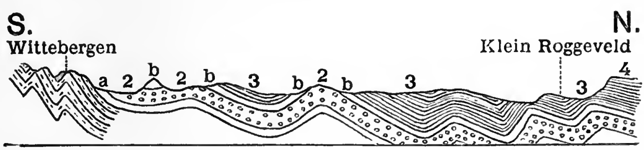


Fig. 14.—Section from the Wittebergen to the Klein Roggeveld, from the folded belt to the Karroo basin. Distance about 13 miles. Vertical scale $\frac{1}{12}$ in. to 1,000 feet.

1. Witteberg series.
2. Dwyka series. { Upper shales (*b*) / Tillite. / Lower shales (*a*).
3. Ecca series.
4. Beaufort series.

Pinchin[2] records a marked unconformity north of Port

[1] A. H. Green, *Report on the Coal-fields of the Cape Colony*, Cape Town, 1883, p. 25.

[2] R. Pinchin, *Q. J. G. S.*, xxxi., Pl. IV., p. 106, 1875.

Elizabeth at about the same horizon as that described by Green, but farther east in the Transkei it has not been seen. The true significance of these observations must remain uncertain till the Eastern Province has been connected with the Western by means of systematic mapping.

The Lower Beaufort beds thus form almost the whole of the mountainous portion of the Western Karroo. Some of the higher zones of this division are represented in Fraserburg, and as far as can be judged the strata there form an outlier, for the same horizons only come in again to the east of Murraysburg.

The Middle Beaufort beds are characterised by the predominance of the aquatic reptilian genus *Lystrosaurus* and the fish *Atherstonia*, but it is not yet known whether the strata containing these fossils can be separated lithologically from the Lower Beaufort. This division appears around Middelburg, Naauwpoort and Cradock and extends north-eastwards past Bethulie into the Orange River Colony at least as far as Senekal, and in an easterly direction along the Winterberg into the Transkei. The zone evidently strikes in a north-easterly direction through the Native Territories, for the remains of *Lystrosaurus* have been discovered in Natal.

Around Naauwpoort there are thick yellow defining sandstones with intercalated greenish shales and mudstones, the latter being at places purple in colour. Near Alandale station there are peculiar sky-blue coloured sandstones.

The *Upper Beaufort* or *Burghersdorp beds* are entirely distinct both lithologically and palæontologically from the Middle and Lower Divisions. The sandstones are yellowish or pale blue in colour, but are somewhat more widely spaced than the sandstones in the lower beds; between them are brilliant red and purple shales, mudstones and thin sandstones with a certain proportion of bluish or greenish shales, which becomes smaller as the base of the Molteno beds is approached. These beds appear around Smithfield and Rouxville in the Orange River Colony, at Aliwal North, Burghersdorp, Steynsburg, Tarka, Queenstown, Cathcart and St. Marks, being probably represented in the Transkei by the Idutywa beds. In this direction the formation becomes more arenaceous, the yellow sandstones becoming thicker and more numerous than in the area to the north-west.

The rocks of this division, especially the red and purple shales, have yielded an abundant reptilian and amphibian fauna, especially around Aliwal North and Burghersdorp, while from the sandstones plant remains have been obtained, indicating a flora distinct from that of the succeeding Stormberg series.

The Beaufort beds have long been celebrated for their extremely interesting reptilian fauna, and so numerous are the descriptions of the fossil vertebrates by Owen, Huxley, Seeley and Broom, that it is impossible here to give even a partial list of references to the papers by these authors. The plant remains have been named by Feistmantel and Seward and some of the mollusca identified by Amalitzky.

The following is a list of the fossils arranged according to the three divisions adopted in this work; the exact localities, and therefore the horizons, from which some of the specimens were obtained, are not known with certainty, but such instances are fortunately rare. The table is taken from one prepared by Dr. Broom,[1] with the names of the plants and invertebrates added.

Upper Beaufort or Burghersdorp Beds.

Plants—

* *Schizoneura*, sp.[2]
* *Thinnfeldia sphenopteroides*, Sew.
* *Taeniopteris carruthersi*, Ten.-Woods.
Danaeopsis hughesi, Feistm.
Odontopteris browni, Sew.
Strobilites laxus, Sew.
Pterophyllum sp. cf. *tietzii*, Schenck.
Stigmatodendron dubium, Sew.
Glossopteris, sp.

Fishes—

Hybodus africanus, Broom.
Ceratodus capensis, S.-Woodward.
,, *ornatus*, Broom.
Helicthys browni, Broom.
,, *draperi*, S.-Woodward.
,, *tenuis*, Broom.
Oxygnathus browni, Broom.
Dictyopyge formosa, Broom.
Cleithrolepis extoni, S.-Woodward.
,, *minor*, Broom.
Hydropessum kannemeyeri, Broom.
Pholidophorus africanus, Broom.
Coelacanthus africanus, Broom.

[1] *A. S. A. M.*, vii., pt. 3, 1909.

[2] Those marked with an asterisk are identical with forms from the Molteno beds and were obtained within less than 100 feet of the base of that formation; see *Q. J. G. S.*, p. 85, 1908.

Amphibia—

Cyclotosaurus albertyni, Broom.
Capitosaurus africanus, Broom.
Trematosaurus kannemeyeri, Broom.
Batracosuchus browni, Broom.
Micropholis stowi, Huxley.
,, *granulata*, Owen.
Bothriceps major, Owen.
,, *huxleyi*, Lydekker.

Reptilia—

Cynognathus crateronotus, Seeley.
,, *platyceps*, Seeley.
,, *berryi*, Seeley.
Gomphognathus kannemeyeri, Seeley.
,, *polyphagus*, Seeley.
Diademodon mastacus, Seeley.
,, *tetragonus*, Seeley.
Trirachodon kannemeyeri, Seeley.
,, *berryi*, Seeley.
,, *minor*, Broom.
Galesaurus planiceps, Owen.
Bauria cynops, Broom.
Aelurosuchus browni, Broom.
Microgomphodon oligocynus, Seeley.
Sesamodon browni, Broom.
Melinodon simus, Broom.
Tribolodon frerensis, Seeley.
Dicynodon latifrons, Broom.
,, *simocephalus*, Weithofer.
,, *ingens?* Broom.
Oudenodon, sp.
Procolophon trigoniceps, Owen.
Thelegnathus browni, Broom.
,, *parvus*, Broom.
Proterosuchus fergusi, Broom.
Howesia browni, Broom.
Palacrodon browni, Broom.
Erythrosuchus africanus, Broom.
Paliguana whitei, Broom.

Mammalia—
Karoomys browni, Broom.

MIDDLE BEAUFORT BEDS.

Crustacean—
Estheria greyi, Jones.[1]

Fishes—
Atherstonia scutata, S.-Woodward.

Reptilia—
Lystrosaurus declinis, Owen.
,, *latirostris*, Owen.
,, *microtrema*, Seeley.
,, *murrayi*, Huxley.
,, *boops*, Owen.
,, *frontalis*, Cope.
,, *mcCaigi*, Seeley.
,, *platyceps*, Seeley.
,, *andersoni*, Broom.
Dicynodon lacerticeps, Owen.

LOWER BEAUFORT BEDS.

Plants—
Schizoneura africana, Feistm.
Schizoneura, sp.
Phyllotheca whaitsi, Sew.
Glossopteris, *browniana* Brongt.
,, *angustifolia*, Brongt.
,, *communis*, Feistm.
,, *tatei*, Feistm.
,, *stricta*, Bunb.
,, *indica*, Schimp. = *Rubidgea Mackayi*, Tate.
,, *retifera*, Feistm.
,, *damudica*, Feistm.

Lamellibranchs—[2]
Palæomutela trigonalis, Amalitsky.
,, sp. cf. *keyserlingi*, Amalitsky.
,, *semilunata*, Amalitsky.
,, *murchisoni*, Amalitsky.

[1] *G. M.*, 1878, p. 100.
[2] Amalitsky, W., *Q. J. G. S.*, vol. li., p. 337, 1895.

Lamellibranchs (*continued*)—
- *Palæomutela plana*, Amalitsky.
- ,, *rhomboidalis*, Sharpe.
- ,, *ovata*, Sharpe.
- *Palæanodonta okensis*, Amalitsky.
- ,, *subcastor*, Amalitsky.

Fishes—
- *Acrolepis digitata*, S.-Woodward.
- *Elonichthys*, sp.

Amphibia—
- *Rhinesuchus whaitsi*, Broom.
- ,, *africanus*, Lydekker.

Reptilia—
- *Pareiasaurus serridens*, Owen.
- ,, *baini*, Seeley.
- *Propappus omocratus*, Lydekker.
- *Tapinocephalus atherstonei*, Owen.
- *Galechirus scholtzi*, Broom.
- *Delphinognathus conocephalus*, Seeley.
- *Titanosuchus ferox*, Owen.
- ,, *cloetei*, Broom.
- *Scapanodon duplessisi*, Broom.
- *Alopecodon priscus*, Broom.
- ,, *rugosus*, Broom.
- *Scylacosaurus sclateri*, Broom.
- *Pristerognathus polyodon*, Seeley.
- ,, *baini*, Broom.
- *Pardosuchus whaitsi*, Broom.
- *Scymnosaurus ferox*, Broom.
- ,, *warreni*, Broom.
- *Glanosuchus macrops*, Broom.
- *Ictidosuchus angusticeps*, Broom.
- *Ælurosaurus felinus*, Owen.
- *Gorgonops torvus*, Owen.
- *Scalaposaurus constrictus*, Owen.
- *Arnognathus parvidens*, Broom.
- *Trochosaurus acutus*, Broom.
- *Hyænasuchus whaitsi*, Broom.

Reptilia (*continued*)—

Lycosuchus mackayi, Broom.
,, *vanderrieti*, Broom.
Ictidosuchus primævus, Broom.
Cynosuchus suppostus, Owen.
Cynodraco serridens, Owen.
Tigrisuchus simus, Owen.
Lycosaurus pardalis, Owen.
,, *tigrinus*, Owen.
,, *curvimola*, Owen.
Cynochampsa laniaria, Owen.
Endothiodon bathystoma, Owen.
Esoterodon uniseries, Owen.
Cryptocynodon simus, Seeley.
Prodicynodon pearstonensis, Broom.
Opisthoctenodon agilis, Broom.
,, *brachyops*, Owen.
Pristerodon mackayi, Huxley.
Dicynodon leoniceps, Owen.
,, *feliceps*, Owen.
,, *pardiceps*, Owen.
,, *testudiceps*, Owen.
,, *tigriceps*, Owen.
,, *jouberti*, Broom.
Kistecephalus microrhinus, Owen.
,, *leptorhinus*, Owen.
,, *planiceps*, Owen.
Ondenodon baini, Owen.
,, *strigiceps*, Owen.
,, *megalops*, Owen.
,, *prognathus*, Owen.
,, *greyi*, Owen.
,, *gracilis*, Broom.
,, *trigoniceps*, Broom.
,, *megalorhinus*, Broom.
Heleosaurus scholtzi, Broom.
Heleophilus acutus, Broom.
Eunotosaurus africanus, Seeley.
Pelosuchus priscus, Broom.
Saurosternon baini, Huxley.

4. The Stormberg Series.

In the east of the Colony and in Basutoland there is a great thickness of sandstone and shales capped by volcanic rocks and broadly distinguished from the underlying Beaufort beds by the presence of a different group of fossil reptiles and plants.

The name Stormberg beds was applied to these rocks by Wyley and Huxley, and it has been used by all later writers.[1] The series is divided up into the following groups in descending order:—

	Maximum thickness.
4. Drakensberg beds (volcanic)	4,000 feet.
3. Cave sandstone	800 ,,
2. Red beds	1,600 ,,
1. Molteno beds	2,000 ,,

The Molteno Beds.

The Molteno beds are first met with at a point a little to the east of Steynsburg and form the higher-lying ground in the Division of Molteno; they extend along the foot of the Stormbergen into Herschel, the Orange River Colony, and Basutoland, and along the base of the Drakensbergen through East Griqualand into Natal.

The formation consists of sandstones, shales and mud stones, the softer beds being much like those of the Ecca and Beaufort, grey, greenish or bluish in colour, but without the calcareous concretions so abundant in the lower groups.

Fossil plants are in places abundant, but seem if anything to be more plentiful in the lower half of the

[1] For detailed accounts of the Stormberg series, see *G. C.*, vii., viii., ix., x.

Molteno beds; silicified wood is common in some of the sandstones.

The sandstones of the Molteno beds are quite unlike any that occur in the lower groups of the Karroo system. In general appearance and in the character of the surface to which they give rise, they resemble the Table Mountain sandstone more closely than any other in the Colony, but they are coarser in grain and much looser in texture. In most localities the quartz grains are coated with a later deposit of quartz with more or less perfect crystalline faces which reflect light well, so that the rock sparkles in sunlight. To such varieties the term "glittering sandstone" has been appropriately given.

Grains of felspar are abundant in these sandstones, sometimes in such quantity that the rock can almost be termed an arkose. The loose texture of the Molteno sandstone has allowed the felspar to weather considerably, and the dull white grains of weathered felspar are always conspicuous constituents of the sandstones, more especially in the finer grained varieties. Rounded or spherical nodules, hollowed out in the centre when the hard outer shell has been broken through, are quite a characteristic feature of the Molteno sandstones. The nodules are formed by the oxidation of pyrites and the deposition of some of the resulting iron compounds in a spherical zone about the lumps of decomposed sulphide. The hard shell is thus due to the addition of the hydrated iron oxides to the cementing material usually sent.

The glittering sandstones form terraces and flat-topped

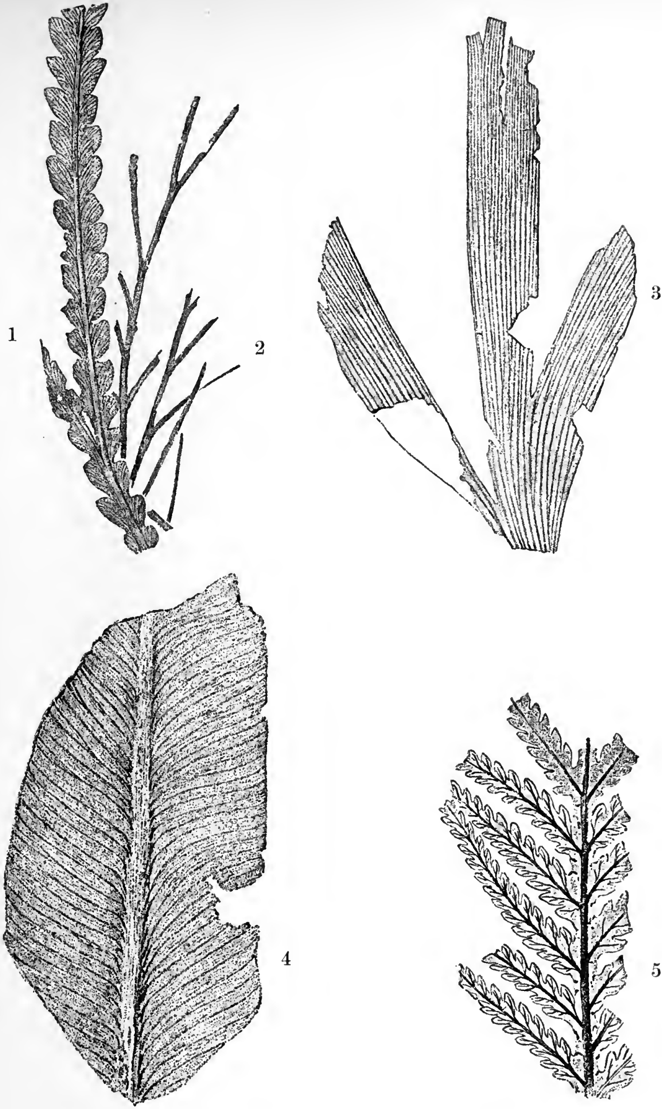


Fig. 15.—Plants from the Stormberg series (Molteno beds) (from Seward).

1. *Thinnfeldia odontopteroides.* Half natural size.
2. *Stenopteris elongata.* Half natural size.
3. *Baiera stormbergensis.* Half natural size.
4. *Taeniopteris carruthersi.* Natural size.
5. *Callipteridium stormbergense.* Natural size.

hills; the slopes below them are usually strewn with great rectangular blocks which have broken off and tumbled down.

The lowest of these coarse glittering sandstones has been termed the "Indwe-Sandstone," and forms a reliable bench-mark from which the horizons of the different coal outcrops can be defined.

The finer grained varieties of sandstone are, as a rule, not so well exposed, as they are friable and tend to form a light sandy soil. They are of a yellowish grey or cream colour and furnish a good building stone. Fencing poles are split from the large sandstone slabs by driving in wedges along straight lines across a slab and breaking it along the row of holes. Posts up to six feet in length are thus easily obtained.

The coarse gritty sandstones occasionally become conglomeratic, the pebbles consisting principally of vein-quartz and of quartzite.

A peculiar feature is the occurrence in the Molteno sandstones of smooth rounded or oval pebbles usually a few inches across but occasionally ranging up to boulders a couple of feet in diameter. They are, as a rule, scattered irregularly through the sandstones, but in the Molteno Division they are specially abundant along a certain horizon and form a bed of conglomerate a few feet in thickness. The pebbles are sometimes found resting upon a coal seam and partly imbedded in the base of the sandstone overlying the coal.

The pebbles are almost entirely of white or brownish, sometimes glassy, quartzites like those of the Witteberg or Table Mountain series. They are most abundant to the south-west of the Stormbergen. Some of these pebbles show pitting externally due to the formation of cubes of pyrites, a layer of which occurs just below the surface.[1] The Molteno beds attain their maximum thickness of a little over 2,000 feet in the Division of Xalanga; in the Stormberg area they are thinner, and in Aliwal North and Herschel it is probable that their thickness does not exceed 1,200 feet.

(For an account of the coals in this formation, see chapter xiv.)

The following is a list of the fossil plants hitherto discovered in the Molteno beds and described by Feistmantel[2] and Seward[3]:—

Schizoneura carrerei, Zeill.
Stenopteris elongata, Carr.
Thinnfeldia odontopteroides, Morr.
,, *rhomboidalis*, Ett.
,, *sphenopteroides*, Sew.
Taeniopteris carruthersi, Ten.-Wood.
Callipteridium stormbergense, Sew.
Cladophlebis (*Todites*) *roesserti*, Presl.
Baiera moltenensis, Sew.
,, *stormbergensis*, Sew.
,, *schencki*, Feistm
Chiropteris zeilleri, Sew.
,, *cuneata*, Carr.
Phoenicopsis (*Desmiophyllum*) *elongatus*, Morr.
Pterophyllum, sp.

The occurrence of some reptilian remains at Molteno was noted by Dunn.

[1] Schwarz, *Rec. Albany Museum*, i., p. 341, 1905.

[2] O. Feistmantel, "Uebersichtliche Darstellung der Geologisch-Palæontologischen Verhaltnisse Süd-Afrikas," *Abh. der königl. böhm. Gesell. der Wiss.*, vii., 3, 1889.

[3] A. C. Seward, *A. S. A. M.*, vol. iv., pt. i., 1903; *Q. J. G. S.*, p. 83, 1908.

The Red Beds.

The Molteno beds pass upwards conformably into a group of strata that are distinguished from them by their prevailing red colour. The name was first used by Mr. Dunn who described the group in the Stormberg area, where they cover a considerable tract of country. The Red beds have been found to extend into Basutoland and Griqualand East, being confined as a rule to the slopes of the mountain ranges.

The most characteristic rocks of the Red beds are purple and red mudstones and shales, but red sandstones and thick beds of yellow and white fine-grained felspathic sandstones are very common. The red colour has in many places been removed from the rocks by the bleaching due to weathering, and as blue and green mudstones are frequently present it is often not easy to draw a line between these and the Molteno beds. The thick glittering sandstones of the latter do not occur in this group. Conglomerates, though rare, are not entirely absent, but they only occur at the base of the division, and the pebbles which are small are of white quartz and quartzite.

Calcareous rocks are frequently found, seldom in definite layers but more commonly in the form of irregular nodules of a bluish or pinkish colour in some of the mudstones. Silicified wood is not uncommon in the Red beds. Lithologically the Red beds show many points of resemblance to the Burghersdorp beds, and like them contain the remains of reptiles, chiefly carnivorous dinosaurs.

Plants such as are found in the Molteno beds do not occur in the Red beds, with the possible exception of the silicified wood.

This group reaches its maximum thickness of 1,600 feet in Elliot; in the Stormbergen and in Aliwal North it thins to about 600 feet, and in Matatiele it has dwindled to not much more than 200 feet.

The fossils hitherto obtained from the Red beds are the following:—

Fishes—
Ceratodus kannemeyeri, Seeley.
Crustacea—
Estheria, sp.
Reptilia—
Euskelesaurus browni, Hux.
Massospondylus carinatus, Owen. } Dinosaurs.
Orinosaurus capensis, Lydd. } Dinosaurs.
Thecodontosaurus browni, Seeley. } Dinosaurs.
Notochampsa longipes, Broom (a crocodile).
Mammalia—
Tritylodon longævus, Owen?

The Cave Sandstone.

The line of junction between the Red beds and Cave sandstone is often abrupt, but not infrequently there are thick beds of white or yellow sandstone at the upper limit of the former, or it may be that the base of the latter is well laminated, so that it is sometimes difficult to draw a sharp line between the two formations. The Cave sandstone is an extraordinarily massive fine-grained rock with bedding planes but feebly developed. The sandstone is largely made up of quartz grains; grains of felspar (mostly microcline) are abundant, and tourmaline, zircon, hornblende and white mica are also present.

Generally the rock is white or cream-coloured on exposed surfaces, but often it is pink or red and sometimes pale blue; frequently it shows a peculiar mottling. It is invariably fine grained and in a few localities its central portion is practically a mudstone. Lithologically it is in no way different from many of the sandstones of the Red beds, except in its finer texture. Generally speaking, the grain of the sandstones becomes finer as one passes from the Molteno beds to the Cave sandstone. In Elliot the Cave sandstone is fully 800 feet thick, but it thins out to north, east and west, seldom exceeding 300 feet in the Stormberg, Basutoland, or Griqualand East. At certain places, as in the north-west of Elliot and in the northern part of Matatiele, the Cave sandstone is not present; it thins out owing to denudation which took place just before the volcanic outbursts, so that the lavas of the volcanic group rest directly upon the Red beds. In Barkly East the Cave sandstone is very often split up by intercalations of lava and volcanic ash.

Fossils are rather rare in this rock, the only finds in Cape Colony being a Dinosaur, *Thecodontosaurus skirtopodus* (Seeley),[1] and a crocodile, *Notochampsa istedana* (Broom),[2] while a band of black shale in the sandstone at Siberia (Wodehouse) yielded *Estheriæ*, small decapod crustacea, and wings of orthopterous insects. Casts of

[1] H. G. Seeley, *Ann. Mag. Nat. Hist.*, Series 6, xiv., p. 411, 1894, originally called *Hortalotarsus*.

[2] R. Broom, *G. M.*, p. 582, 1904.

the footprints of Dinosaurs have been found near Jamestown and near Morija in Basutoland.

The fish *Semionotus capensis* (S.-Woodward), from near Ficksburg in the Orange River Colony, seems to occur in the Cave sandstone; and probably the same genus has been found at Masitisi in Southern Basutoland.

The Cave sandstone gives rise to very remarkable features on the slopes of the mountains and on the tops of spurs projecting from the main ridges. It tends to weather into huge pillars and irregularly shaped masses often with the lower portion hollowed out to form a shallow cave, a characteristic that gave the rock its name. Such rock shelters were frequented by some primitive people, whose former presence is indicated by agate chips, fragments of ostrich egg-shells, and coarse pottery, and especially by more or less realistic paintings of men and animals done in red, yellow and black colours upon the pale surface of the rock.

Above the village of Elliot the hard yellow sandstone forms buttresses and pillars over 300 feet high, while in many places along the Drakensberg, and again in Herschel and Basutoland, it forms yellow cliffs and precipices capped by dark-coloured basaltic lavas. There is no rock in the country that produces such peculiar features as the Cave sandstone where typically developed (see Plate XIV.).

The Drakensberg or Volcanic Beds.[1]

Before the close of the period represented by the Stormberg sedimentary rocks volcanic activity com-

[1] *G. C.*, vii., p. 37; viii., p. 190; ix., p. 102; x., p. 130.

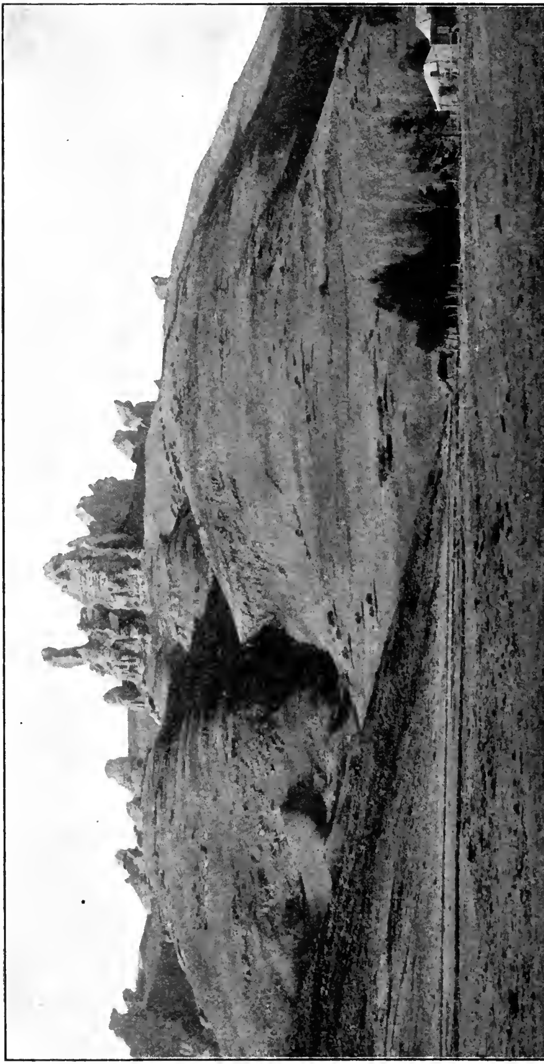


Plate XIV.—View of the Drakensberg north of Elliot, rising nearly 2,000 feet, showing slopes of Red beds, with sheet of intrusive dolerite seen in kloof in centre, crowned by the Cave sandstone, the pillars of the latter being nearly 300 feet in height.

menced in the north-eastern part of the Colony. Near Molteno there are a few hills capped by volcanic rocks, outliers of a formation which is found covering an enormous area in Barkly East, Herschel, the interior of Basutoland, and along the boundary between that country and East Griqualand and Natal. Volcanic rocks, in all likelihood belonging to this formation, are found in the Lebombo Mountains, the Bushveld area of the Transvaal, and Rhodesia.

The volcanic beds form the highest parts of the country in which they occur; seldom indeed does their base drop as low as 5,000 feet above sea level. They constitute a plateau which has been greatly dissected by the upper tributaries of the Orange River. In places it rises to over 10,000 feet above sea level. The Drakensbergen are the southern edge of the plateau and overlook the Transkei, Griqualand East and Natal. The escarpment extends over 350 miles, and rises from 2,000 to 6,000 feet above the country at its foot.

In the Cape Colony the volcanic rocks rarely reach 3,000 feet in thickness, but near Ongeluk's Nek (Matatiele) there must be quite 4,000 of them; while Mr. Churchill measured a vertical thickness of 4,500 feet on the Mont aux Sources in Natal.

By far the greater part of the group is formed of lava streams, but in Barkly East and Elliot sandstones, bedded tuffs, and agglomerates are represented towards the base of the formation.

Although the relationship between the Cave sandstone and the volcanic beds is a very intimate one, the former containing in places intercalated lava-flows, there are

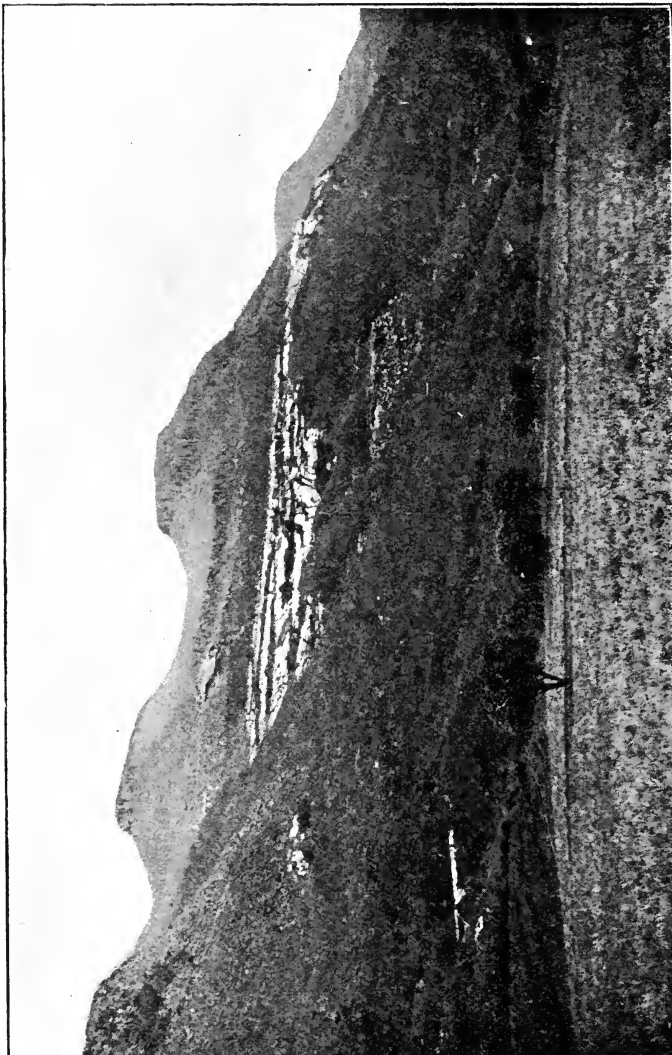


Plate XV.—A spur of the Drakensbergen near N'quatsha's Nek, Matatiele. The rocks forming the lowest slopes belong to the Red beds, the white rock is the Cave sandstone, and that on the summit is doleritic lava of the Volcanic group. The bedding of the Cave sandstone is well shown.

several localities where the volcanic rocks rest unconformably upon the sedimentaries.

In the western part of Elliot, under Xalanga Peak, the lowest lavas rest upon the Cave sandstone for a certain distance and then pass downwards at a moderate angle over an apparently eroded surface of that rock until they rest directly upon the Red beds. To the north-east there is a band of red sandstone and shale rather under fifty feet thick intercalated between the lower groups of lavas for a distance of some ten miles round the head-waters of the Qokama River. The lava below the Red sandstone band lies upon the Red beds. At Siberia, some distance to the north-west, the Cave sandstone has suffered faulting and erosion prior to the outpouring of the lavas; above the main bed of Cave sandstone in this locality there are three other sandstone bands interbedded in the lavas and traceable for considerable distances.

In Barkly East this alternation of sedimentary and igneous material is very marked, and the history of the eruptions can in consequence be worked out in detail by following up these thin and often remarkably regular intercalations of sandstone and tuff.

The presence between lava-flows of sedimentary material, frequently passing both vertically and laterally into volcanic ash, the presence of masses of lava (bombs) embedded in fragmental rocks, and the layers of pipe-amygdaloid at the bases of the individual lava-flows, all indicate that the earliest volcanic eruptions took place under water. The outbursts of molten rock must have been followed by intervals during which sedimentation proceeded more or less continuously.

Around the great Belmore volcano between Barkly and Rhodes a large area appears to have subsided after the earliest eruptions, the basin so produced being subsequently filled by lavas and tuffs. A similar area of subsidence was found along the Kraai River west of Barkly.

Over a wide area in the south-west of Barkly a thick bed of reddish rudely stratified volcanic ash directly overlies, and at places grades into the Cave sandstone. At the Barkly Pass, in the vicinity of the large volcanic neck on the farm Tulloch (Elliot), the ash band reaches its maximum thickness of 350 feet. The section at the Tembu Pass, a few miles to the east, is as follows:—

5. Bedded lavas	350 feet
4. Purple stratified ash	80 ,,
3. Cave sandstone	30 ,,
2. Bedded lavas	50 ,,
1. Cave sandstone	800 ,,

Further to the east the ash-beds disappear and the lavas rest directly upon the Cave sandstone, which is no longer divided into two portions.

In the Stormberg area, according to Mr. Dunn, ash-beds are present towards the base of the volcanic group. In Herschel, Basutoland, and Griqualand East the development of ash-beds between the lava-flows is very restricted. In Matatiele, on the crest of the mountain behind the farm Eyrie, there are two bands of sandstone and shale intercalated between thick flows of lava. The section through the upper part of the mountain at this locality is in downward order:—

6. Lavas	130 feet
5. Red sandstones and shales	20 ,,
4. Lavas	70 ,,
3. Shales	40 ,,
2. Lavas	630 ,,
1. Cave sandstone	100 ,,

The red sandstones both here and in Barkly consist of fragments of altered lava and volcanic glass mixed with grains of quartz, microcline felspar and zircon, probably derived from the same source as the materials composing the Cave sandstone. Such beds as these can be regarded as partly of ordinary detrital and partly of volcanic origin; they were undoubtedly deposited under water, and thus support the evidence already quoted to that effect. Tuffs play a very insignificant part in this formation, however.

The basaltic lavas are dark greyish- or purplish-brown in colour, and are usually evenly bedded. The compact doleritic varieties sometimes show a rude columnar structure and are less prone to alteration than the amygdaloidal varieties. The latter weather more readily and give rise to *débris*-covered slopes on the mountain sides rather than to kranzes.

The Petrography of the Lavas.[1]

As a rule the lavas have the composition of basalts, but in Barkly they are more nearly allied to the augite-andesites, while from a few localities still less basic varieties, enstatite-andesites, have been obtained.

The mineral constituents are similar in both compact and vesicular varieties, but the proportions in which

[1] *G. C.*, vii., p. 65; and ix., p. 130.

they are present vary. The felspar of the earlier generation is most frequently labradorite, that of the second is usually andesine; the augite is commonly colourless; olivine is often present, but seldom in quantity, and is more or less changed to greenish serpentine; magnetite is always, and apatite often, present, and occasionally enstatite or a green augite. Brown glass containing microlites is found in many of the lavas.

Many of the vesicular lavas are basalts having a varying amount of glass and microcrystalline base, in which are embedded more or less well-formed crystals of olivine, augite and felspar; the enstatite-andesites of the Belmore volcano are highly glassy and show fluxion and perlitic structures. The doleritic lavas may possess a small amount of residual glass; the felspar is either in fair-sized porphyritic crystals between which small augites and felspars lie, or in smaller laths partially or wholly enclosed by masses of augite. The last-mentioned type of rock is very similar in character to the dolerite of the intrusive sheets and dykes of the Karroo, but the ophitic structure is rarely so well developed in the Drakensberg lavas as in the latter. There are no coarsely porphyritic lavas.

The specific gravity of the doleritic varieties ranges from about 2·8 to 2·95, and is less than that of the Karroo dolerites, which range from 2·95 to 3·0.

The amygdaloidal lavas have their steam-holes as a rule filled in with secondary minerals such as calcite, chalcedony (agate) or zeolites, amongst which heulandite, stilbite, thomsonite and scolecite have been recognised. A layer of green chlorite or delessite sometimes lines cavities which are filled in with one or more of the above-mentioned minerals.

The amygdales may be more or less spherical or irregular in shape. In certain varieties, known as pipe-amygdaloid, there are pipe-like amygdales from four to ten inches long, usually branching downwards. They are found in layers at the base of certain of the flows, separated from the underlying rock by an inch or two of lava in which the steam-holes are of the usual type. The pipes are more or less perpendicular to the base of the flow, but sometimes they are considerably inclined.

It is probable that these tubular structures have been produced by the flowing of the lava when in a viscid condition over a moist surface of lava, ash or sandstone.[1] Another explanation is that the whole of the vapour which formed the pipes was in the lava at the time of its extrusion, and that it only had time to expand after the lava poured over the surface, or that the bulk of it was only released on the temperature of the rock falling to the certain critical point.[2] On this view it is difficult to understand the localisation of the rows of pipes.

The Volcanic Necks.

From areas that have been already mapped, about 100 vents filled with lava, agglomerate, or tuff have been described, and there can be no doubt that many more await discovery. Three of these were observed by Mr. Dunn many years ago; at least fifteen occur in Wodehouse, twenty in Barkly East, seventeen in Elliot, twenty-two in Herschel, nineteen in Matatiele, and

[1] *G. M.*, 1907, p. 13. [2] *G. C.*, vii., p. 57.

several in Aliwal North, while a few were incidentally noticed in Basutoland and in the Orange River Colony.

In none of these vents is the crater form still preserved, for in every case the necks have been laid bare by denudation. They are thus differently situated with regard to the surrounding beds according to the amount of denudation to which the latter have been subjected. Some of the necks, as in Barkly East, are still surrounded by volcanic beds, but the majority are in contact with the Cave sandstone or else with the lower subdivisions of the Stormberg series.

The necks are distributed over a wide, and so far as can be judged, fairly well-defined area or belt. The southern limit of this area is a line drawn through Sterkstroom, Indwe, Xuka and onwards towards Natal at a short distance from the foot of the Drakensberg escarpment. The northern boundary is not well known, but it is probably near a line drawn from Steynsburg through Aliwal North and Zastron. The existence of several volcanic vents in Basutoland[1] has been recorded, but with these exceptions the distribution of the pipes outside Cape Colony is quite unknown.

The pipes within the area just defined are distributed in a most irregular manner, usually in little groups, while sometimes three or more lie arranged along a straight line. Such an absence of definite or orderly arrangement is paralleled by the Carboniferous volcanoes of Central Scotland, the Permian vents of Fifeshire, those of the Eifel, the Swabian Alps and the Auvergne.

In regard to size and shape the necks show great

[1] S. S. Dornan, *G. M.*, p. 113, 1908.

variation. The smallest one known was found in Matatiele, and is only four yards across; the great majority exceed 100 yards in diameter, while there are a few which are as much as a mile wide. Some are circular in outline, while others again are much elongated.

In their contents also the pipes vary greatly. A few necks, mostly small ones, are plugged entirely with doleritic lava; a larger example is to be found close to the Gatberg in Elliot.

Many of the pipes are now filled with a light or dark bluish agglomerate containing fragments of lavas and of sedimentary rocks, the latter being usually derived from the Stormberg beds, though Pre-Karroo quartzites are occasionally represented.

The matrix of these agglomerates is largely composed of grains of quartz and felspar, derived from a sedimentary or a granitic rock, as both orthoclase and microcline are abundant, along with zircon, rutile, hornblende, garnet, muscovite, and tourmaline; these are minerals that do not occur in the lavas. With them are others, plagioclase felspar especially, which are important constituents of the basalts, and of which both small and large fragments are frequently abundant in the agglomerates. Pieces of charred wood have also been found; they may be the remains of trees which grew on the slopes of the volcanoes during periods of quiescence. On a renewal of activity fragments of these trees fell into the crater and became embedded in the breccias.

Not uncommonly finely divided sedimentary material so predominates that the tuff filling the neck closely resembles the Cave sandstone, not only from a distance but even in the hand specimen. Such necks are well represented in Wodehouse and Herschel, and are all the more remarkable considering the extremely poor development of siliceous tuffs interbedded with the lavas, a state of things which would hardly obtain were the Drakensberg vents strictly comparable with modern lava and ash volcanoes, or those of Devonian and Carboniferous age in the British Isles. In the east of Herschel there is a peculiar dyke several miles in length formed of this siliceous tuff cutting through a plateau of Red beds and Cave sandstone.

The bigger pipes are filled partly by agglomerate and partly by lava, and in a few cases there is a connection still existing between the igneous rock in the vent and the lava-flows which have obviously issued from the volcano. Generally, however, denudation has proceeded so far that the original connections have long since been destroyed.

The Belmore volcano in Barkly East is about three-quarters of a mile in diameter and is entirely surrounded by Cave sandstone, which dips inwards towards the centre of the pipe. The agglomerate is cut by sills of dolerite and glassy enstatite-andesite, while the central plug is formed by a great mass of the latter rock with columnar structure. On the north and east there are alternations of tuffs and basaltic and andesitic lavas dipping at high angles, together with masses of coarse agglomerate. The more acid lavas cut the basaltic varieties and are later in age. The lavas forming the hills round about are split up by intercalations of sandstone and ash, while a bed of the latter about half a mile north of the volcano contains large oval masses of lava, apparently bombs which were ejected during one of the eruptions. The Belmore volcano shows signs of repeated activity and in great likelihood had a long life.

Dykes of Karroo dolerite cut through a number of the necks in Elliot and Wodehouse and occasionally traverse the lava-flows as well. In this area there are no great fissures through which the lavas may have reached the surface.

Prof. Schwarz, however, came to the conclusion that some of the flows in Matatiele issued from fissures which are now filled with dolerite and are dykes cutting both the sedimentary rocks and the lower lavas.[1] The largest of these dykes is about fifteen miles long and a mile wide at its broadest part. It runs parallel with the main ridge of the Drakensberg from Deer Park to George Moshesh's country, and on its southern side the amygdaloidal lavas cut through by it are turned upwards in a similar manner to the upturning of sedimentary beds round the walls of a volcanic neck. Along the northern wall of this dyke the lavas are much disturbed and crushed. These are features which have not been noticed in the usual dolerite dykes in the Colony; in the latter the molten rock seems to have risen quietly without having to exert a force capable of crushing or disturbing the rocks forming their walls. The formation of the dolerite-filled fissure on the Drakensberg ridge was evidently accompanied by explosive action, and through it may have been poured a large part of the lava which

[1] *G. C.*, vii., p. 48.

now builds up the higher portion of the ridge and a great bulk of rock that has disappeared under the ceaseless attack of the weather.

The largest of the Matatiele pipes is on the farm York; it is about a mile in diameter, and it has been cut in two by a tributary of the Mabele River. The vent is filled partly with amygdaloidal and doleritic lavas, and partly with agglomerate. The dolerite was the first rock to flow from the pipe, and it is still connected with a columnar flow of dolerite that lies upon the Cave sandstone. The doleritic rock was succeeded by amygdaloidal lavas, part of which are still preserved in the lava-flows, 4,000 feet thick, near Ongeluk's Nek. Near the volcano the lava contains large masses of sandstone and shale, baked and converted into porcellanite by the heat of the lava. There are some baked shales that Prof. Schwarz regards as having been formed in temporary lakes or streams on the volcano itself, and subsequently hardened by fresh flows of lava. Brown, gritty soil is preserved between some of the lava streams that issued from this vent, indicating that the volcano, even if it started its activity below the water level, piled up its lava sufficiently to form a land surface. The agglomerate is dark blue in colour, and includes large numbers of fragments of lavas and sedimentary rocks; this material is probably the result of the final explosive outburst of the volcano. Evidence of the long duration of the activity of this vent is given by the old valleys carved out of some of the lava-flows and filled in by later ones.

Taking into consideration the great thickness of lavas in the Drakensberg and in Basutoland, the scarcity of intercalations and the absence of more normal agglomerates from the necks is certainly remarkable, because the great volcanoes of the present day consist chiefly of fragmental tuffs which thin out quickly in all directions, though they may cover wide areas.

From the existence of now widely distant outliers of lavas apparently of Stormberg age in the Transvaal, Portuguese East Africa and Rhodesia, it is clear that this formation must have at one time covered an enormous tract of country. Whether these northern lavas issued from necks or from fissures is unknown, but it is not unlikely that there was here a parallel to the extensive flows of the Deccan area of India and of Idaho in North America, in both of which volcanic necks appear to have played a very subordinate part. The Drakensberg type of volcanism may possibly, therefore, have been intermediate in nature between the normal eruptions of the present day and those that produced the lavas of the Deccan and of the Western States of America.

The part played by the volcanic episode in the geological history of the country can be more conveniently dealt with in chapter xiii., where its relation to previous and subsequent events will be explained.

5. The Correlation of the Karroo System.

The correlation of the various members of the Karroo system with foreign beds is attended by many difficulties, due chiefly to the fact that the Karroo beds were not deposited in the sea. Marine forms of past ages are as a rule better known than the land and fresh-water organisms that lived contemporaneously with them, because the former have been preserved in far greater numbers than the latter; this can easily be explained when we consider the very small chance that land animals and plants have of being covered up by mud or other sediment before decomposition destroys them. It is only near the mouths of large rivers laden with silt and in regions of internal drainage, *i.e.*, without outflow to the ocean, that such remains are likely to be entombed; and, unless the areas in question are gradually sinking, and thus allow the accumulation of much sediment, the deposits formed will probably soon be swept away. The Karroo formation is a very remarkable example of a thick group of beds laid down in fresh water, or at any rate not under the sea, and in it are preserved scanty remains of a very long succession of animals and plants which lived mainly on land. It is a generally recognised fact that animals and plants that live on the land and in fresh water vary more in different regions than the marine forms in the sea round the shores of the same countries, because the conditions of life are subject to greater changes and there is on the whole less freedom of movement in the case of the inhabitants of the land. This results in the land and fresh-water species having a narrower distribution than the marine, and hence in their being of less general use than the latter for the purpose of correlating distant strata. Another unfortunate circumstance is that the only available plant remains cannot so certainly be assigned to well-defined species as the hard parts of marine animals that are used for correlation purposes in the marine beds of Carboniferous and Permian age.

The Witteberg beds which were laid down immediately before the lowest beds of the Karroo formation in the south of the Colony afford very little help, for they are singularly barren of fossils; the few casts of plant stems which they have yielded are of no real use in determining the age of the beds in which they occur.

The important fact in attempting to correlate the lower beds of the Karroo formation is that a peculiar flora, called the Glossopteris flora [1] from the name of its most widespread genus, occurs in them and in association with the Dwyka glacial beds. In India, South America, and the Australian region the same kind of plants have been found associated with a similar glacial deposit.

In India [2] the glacial boulder-beds (Talcher) lie unconformably upon older rocks in the Peninsula and are followed by shales and sandstones containing the Glossopteris flora, as in the case of the Dwyka tillite in the north of Cape Colony; in the Salt Range similar boulder-beds lie unconformably upon older rocks, but in this case they are overlain by strata containing Permian or Upper Carboniferous marine fossils, some of which are identical with Australian species; this marine fauna gives place to a group of unfossiliferous rocks which are

[1] For a very useful and complete account of this flora see the British Museum Catalogue of the Glossopteris Flora, by E. A. Newell Arber, London, 1905. Dr. David White prefers the name Gangamopteris Flora.

[2] Holland, T. H., in the *Imperial Gazetteer of India*, vol. i., 1907, pp. 70-71.

followed by the *Productus* limestones characterised by the abundance of individuals and species of that genus. Near Srinagar in Kashmir [1] three typical genera of the Glossopteris flora, *Gangamopteris*, *Psygmophyllum*, and *Cordaites* (*Noeggerathiopsis*), lie conformably below beds, called the Zewan stage, which contain *Protoretepora ampla* and *Productus cora*.

The bearing of the evidence from India on the precise horizon of the glacial beds and the Glossopteris flora is a matter of dispute, for there are differences of opinion as to the age of the marine beds themselves. The opinion of the Indian Survey is that the marine beds concerned are of Upper Carboniferous age, while Koken [2] and Frech [3] place them in the Permian. The occurrence of *Mesosaurus* in the Upper Dwyka shales is evidence in favour of the Permian age of these beds,[4] because reptiles in Europe and North America are first met with in the Permian. Thus there is no definite evidence as to the age of the Dwyka tillite; it may belong either to the Upper Carboniferous or to the Lower Permian.

In the South American region strata which closely resemble those of the Karroo formation occur in Southern Brazil, the Argentine and the Falkland Islands. In

[1] Hayden, H. H., "The Stratigraphical Position of the Gangamopteris Beds in Kashmir," *Rec. Geol. Surv. Ind.*, xxxvi., pp. 23-39, 1907; Seward, A. C., "Permo-Carboniferous Plants from Kashmir," *ibid.*, pp. 57-61.

[2] Koken, E., *N. J. f. Min.*, etc., Festband, 1907, p. 446.

[3] Frech, F., *Lethaea Geognostica*, ii., fig. 4, 1902, p. 590 (quoted from D. White's Report).

[4] Broom, R., "Classification of the Karroo System," in Addresses and Papers read at the joint meeting of the British and South African A. A. S., Johannesburg, 1905, vol. ii., p. 38.

these three countries boulder-beds, supposed to be of glacial origin, lie at or near the base of a group of rocks which contain typical genera and species of the Glossopteris flora.

The most complete account of any of these rocks is that published by the Brazilian Government,[1] and therefore more will be said here about that region than the others. The Brazilian formation is called the Santa Catharina system, which is over 4,000 feet thick, and is subdivided as follows :—

Sta. Catharina system	São Bento series	Volcanic rocks (basalts, etc.) São Bento sandstone Rio do Rasto red beds (*Scaphionyx*)
	Passa Dois series	Estrada Nova beds Iraty shales (*Mesosaurus*)
	Rio Tubarão series	Palermo shales Rio Bonito beds (*Glossopteris*, *Sigillaria brardi* etc.) Orleans conglomerate (*glacial*)

The Orleans conglomerate is in many respects like the Dwyka; it lies either directly and unconformably upon beds containing *Leptocœlia flabellites* and other Lower Devonian fossils, or upon granite, or there may be some sandstone and shale below the conglomerate.

[1] Final Report of the Coal Commission presented to Dr. L. Müller; by I. C. White; Rio Janeiro, 1908. This contains not only an account of the Geology of Southern Brazil with regard to the coal supply, but descriptions of *Mesosaurus* by J. H. Macgregor, of *Scaphionyx* by A. Smith-Woodward, and of the fossil plants by D. White, who also gives a valuable discussion on the correlation and climatic questions raised by the work of the Commission. See also D. White, *Journal of Geology*, xv., 1907, p. 615.

Upon the Orleans conglomerate lie the Rio Bonito beds, which are the productive coal measures of the district. They contain many fossil plants found also in the Ecca and Beaufort beds of South Africa, including the following genera, *Phyllotheca*, *Glossopteris*, *Vertebraria*, *Gangamopteris*, *Cardiocarpus*, *Cordaites*, *Schizoneura*, *Sigillaria*, *Lepidodendron*. The Iraty shales are black, and seem to be similar in character to the black shales of the Upper Dwyka, and they also contain *Mesosaurus* ; *Stereosternum* is found on the same horizon farther north. It is interesting to note that in Brazil *Mesosaurus* occurs above the beds containing the Glossopteris flora, and not below them as in South Africa. The reptilian fauna of the Beaufort beds is scarcely represented in Brazil, though as the Sta. Catharine system covers a very large area (probably even larger than that of the Karroo beds), and has only been partially examined, more typical genera may yet be discovered. An unconformity is possibly present at the top of the Passa Dois series, however. The *Scaphionyx* from the Rio do Rasto beds is allied to *Erythrosuchus* from the Upper Beaufort beds. As in South Africa, there is a thick group of volcanic rocks of basic and intermediate composition at the top of the system.

Dr. David White regards the flora of the Rio Bonito beds as belonging to the Permian, and places the Orleans beds in that system also, but cannot lay down the limit between Permian and Trias in South Brazil.

In the Argentine the Bajo de Velis beds contain *Gangamopteris*, *Neuropteridium* and *Cordaites*, while these also occur, together with *Phyllotheca* and *Glossopteris*, in the Sierra los Llanos in beds lying upon a thick conglomerate.[1]

In the Falkland Islands there has been found a glacial boulder-bed overlain by beds containing *Glossopteris*, *Phyllotheca* and, perhaps, *Schizoneura*.[2]

Perhaps the most interesting comparison can be drawn between the Beaufort fauna and flora and those of the Permian formation of Russia. *Palæomutela* and *Palæanodonta* are two genera of probably fresh-water mollusca that are common to the Russian and South African beds; of the first-named genus four species from the Karroo beds were determined by Amalitzky to be identical with Russian forms, *viz.*, *P. trigonalis*, *P. semilunata*, *P. murchisoni*, and *P. plana*, while seven other species are very closely allied to others from Russia; of *Palæanodonta* two species are common to the two formations, *P. okensis* and *subcastor*.[3] Amalitzky has also found *Pareiasaurus*, *Dicynodon*, *Oudenodon* and large Therocephalian reptiles in lenticular beds within the Permian strata on the Dwina River associated with *Glossopteris* and *Gangamopteris*.[4] Both above and below the horizon on which these characteristic Karroo genera occur there are limestones containing marine species of Upper Permian age. These discoveries go far towards settling the age of the Beaufort beds relatively to the European rocks.

[1] Kurtz, F., *Rec. Geol. Surv. India*, xxviii., p. 111, 1895; Bodenbender, W., *Zeitsch. d. Deutsch. Geol. Gesellsch.*, xlviii., p. 183, 1896; *Zeitsch. f. prakt. Geol.*, 1896, p. 120.

[2] Nathorst, *Bull. Geol. Inst. Upsala*, vol. vii., 1906, p. 72, and J. Halle, *G. M.*, 1908, p. 264.

[3] Amalitzky, W., *Q. J. G. S.*, p. 337, 1895.

[4] Amalitzky, W., *Sur les Fouilles de* 1899 *de Débris de Vertébrés dans les Dépôts Permiens de la Russie du Nord*, Warsaw, 1900.

In the Australian region[1] glacial boulder clays are found at the base of the beds containing the Glossopteris flora in Victoria (Bacchus Marsh, Wild Duck Creek, etc.), New South Wales, Queensland, South Australia, West Australia and Tasmania. The most complete succession is found in New South Wales, where there is a great development of strata containing marine fossils of Upper Carboniferous or Permian age. The lower portion consists of an Upper and a Lower Marine formation between which lies the Greta coal series with *Glossopteris*, *Gangamopteris*, etc. Glacial erratics have been found in both the Upper and Lower Marine beds,[2] and in places there are well-developed glacial horizons.

Over the greater part of Australia there is an unconformity at the base of these formations carrying glacial erratics; in certain areas, however, they pass downwards without a break into strata containing marine Carboniferous fossils.

Prof. Seward[3] has pointed out that while the Palæozoic flora characterised by lepidodendroid plants existed in the southern hemisphere before the Glossopteris flora, the latter probably originated in the south, and flourished there almost to the exclusion of the older plants during the Permo-Carboniferous period, though the older flora lived on in the northern hemisphere where the Glossopteris flora only arrived in late Permian and Triassic

[1] Edgeworth-David, T. W., *Q. J. G. S.*, lii., p. 289.

[2] For a detailed account of these beds see the same author in Memoir, No. 4, *Geological Survey of New South Wales*, 1907.

[3] Presidential address, Section K, Southport Meeting of the British Association, 1903.

times. In South Africa and Brazil the two floras intermingled to some extent, though the Glossopteris was predominant. He favours the view that climatic conditions were responsible for the almost complete disappearance of the lepidodendroid vegetation in the south, and thinks that though the cold climate indicated by the glacial beds may have been an important factor, it is perhaps more likely that the drier continental conditions in the south, then so different from the low-lying swampy countries in which *Lepidodendron* and its allies lived in Upper Carboniferous times in North America and Europe, determined the issue.

Recently[1] *Eurydesma globosum* and a *Conularia* have been found in the shales above the Dwyka tillite near the Fish River in German South-West Africa; *Eurydesma* is a thick-shelled lamellibranch known from Australia[2] and India[3] in association with marine fossils (including *Conularia* in the Salt Range) above the boulder-beds of glacial origin. This discovery gives the first indication of the position of the sea near South Africa in Dwyka times.

Lately reptiles allied to those from the Beaufort beds have been discovered in Madagascar.

The reptiles of the Lower and Middle Beaufort beds are very poorly represented in India by *Dicynodon* and *Ptychosiagum* (*Lystrosaurus*), in the Panchet formation, and those of the Upper Beaufort by *Hyperodapedon*

[1] Schroeder, H., *Jahrb. d. Königl. Preuss. Geol. Landesanstalt*, xxix., Th. i., Hft. 3, 1908, p. 694.

[2] David, T. W. E., *Memoirs of the Geol. Survey of New South Wales, Geology*, No. 4, 1907.

[3] Koken, E., *Centralblatt für Min.*, etc., 1904, pp. 97-107.

(allied to *Howesia*) and *Belodon* in the Maleri beds (Upper Gondwana).

The fauna of the Burghersdorp beds[1] (Upper Beaufort) has distinctly Triassic representatives in the labyrinthodont *Cyclotosaurus albertyni* allied to *C. robustus* from the Keuper of Würtemberg, the phytosaur *Erythrosuchus africanus* allied to *Belodon*, and the fishes *Cleithrolepis*, *Dictyopyge*, *Pholidophorus*, *Oxygnathus* and *Hybodus*.

The Hawkesbury series[2] of New South Wales contain labyrinthodonts and fishes closely related to those of the Upper Beaufort, and also *Glossopteris* and *Thinnfeldia*.

The flora of the Molteno beds[3] was shown by Feistmantel and Seward to be of Rhætic age, and is similar to that of the Wianamatta beds of New South Wales, the Rhætic of Tonkin, Cacheuta in Argentina and of Honduras.

The Stormberg beds above the Molteno group must be of Jurassic age, but fossils are scarce. The crocodile *Notochampsa* from the Red beds and Cave sandstone is not closely allied to any European form, but seems to be a degenerate descendant of a *Pelagosaurus*-like reptile. *Pelagosaurus* itself comes from the Upper Lias, so *Notochampsa* may well be of about the same age.[4]

The following table represents broadly the correlation of the Karroo system with similar formations elsewhere :—

[1] Broom, R., *Ann. S. A. M.*, viii., pt. 3, 1909.

[2] Smith-Woodward, A., *Mem. Geol. Surv. N.S.W.*, *Palæontology*, No. 4, 1890.

[3] Feistmantel, O., *Abh. d. Kgl. böhm. Gesellsch. d. Wiss.*, vii. Folge, Bd. iii., Prag., 1889 ; Seward, A. C., *Ann. S. A. M.*, iv., pt. i. ; and *Q. J. G. S.*, lxiv., p. 83.

[4] Broom, R., Papers read at the joint meeting of the B. and S. A. A. A. S. in South Africa, 1905, vol. ii., p. 42.

Cape Colony.		Brazil.		India.		New South Wales.		Europe.
Stormberg series.	Drakensberg beds (volcanic).	São Bento series.	Volcanic rocks.	Upper Gondwanas.	Rajmahal.			Lower Jurassic.
	Cave sandstone.		São Bento sandstone.					
	Red beds.							
	Molteno beds.				Kota-Maleri.		Wianamatta beds.	Rhætic.
Beaufort series.	Burghersdorp beds.		Rio do Rasto beds.				Hawkesbury series.	Trias.
	Middle Beaufort beds.		Estrada Nova series.	Lower Gondwanas.	Panchet.	Upper Coal Measures.	Newcastle.	Permian.
	Lower Beaufort beds.				Damuda		Dempsey.	
Ecca series.							Tomago.	
Dwyka series.	Upper shales.		Iraty shales.				Upper Marine series.	
			Palermo shales.					
	Boulder-beds.		Rio Bonito beds.		Talcher.		Greta series (Lower Coal Measures).	
			Orleans conglomerate.					Upper Carboniferous.
	Lower shales.		Sandstones and shales.				Lower Marine series.	

CHAPTER VIII.

THE REPTILES OF THE KARROO FORMATION.

By R. Broom.

During the whole of the Permian and Triassic periods continental conditions prevailed over at least the greater part of what is now South Africa, and in the lacustrine deposits then formed the remains of reptiles, amphibians and fishes are by no means uncommon. In probably no part of the world is there a formation of greater interest to the palæontologist, for here in the 14,000 feet or so of strata we have beds which when fully studied will yield us a continuous history of the land animals of one part of the world during a period of possibly over 2,000,000 years, and there could be no period in the world's history more interesting to us than that which saw the dawn of all the reptilian orders, and of the birds and mammals, if we except that in which man himself appeared.

As the Karroo formation occupies about 200,000 square miles, great tracts of which are covered by superficial deposits or by dolerite, and as it is only here and there on slopes and in water-courses that the fossiliferous beds are exposed, it will readily be understood that it will take very many years before more than a preliminary account can be given of the Karroo faunas. At present we only know enough to give merely a general account of the commoner forms found at the different periods.

The earliest reptile met with occurs in the Upper Dwyka shales, and is called *Mesosaurus*. It is a small aquatic form about eighteen inches in length with a long narrow pointed head, a very long tail, and feeble limbs. By most European authorities it has been looked upon as a primitive sort of Plesiosaur, but Osborn, Cope, Baur and McGregor, in my opinion, are right in regarding it as an early type of Rhynchocephalian in no way nearly related to the Plesiosaurs, and in many points of its structure it resembles *Procolophon* hereafter mentioned. Whatever be its affinities, it is agreed by all to be a true reptile, and one which has undergone considerable specialisation. As in no part of the world has any reptile ever been discovered in beds earlier than Permian, we seem justified in concluding that the Upper Dwyka shales are not older than Lower Permian. *Mesosaurus* is of further interest in that an almost identical form occurs in Brazil.

In the 2,000 to 3,000 feet of strata above the Dwyka which have been called the Ecca series reptilian remains are very rare. So far only two genera have been described, *Archæosuchus*, a large carnivorous form perhaps allied to *Titanosuchus* mentioned below and *Eccasaurus*, a huge rhynchocephaloid reptile—by far the largest known. The imperfect remains of at least two other animals are known but have not yet been described.

Immediately above this comparatively barren series of strata we come to beds in which fossil reptiles are relatively plentiful, and sufficient is known to give a fair idea of the fauna. *Pareiasaurus*, the most characteristic member, is a huge, heavily-built reptile about nine feet long and standing three feet in height. The skull has the temporal region roofed over as in labyrinthodonts, and the bones are sculptured in a somewhat similar manner, but the structure of the palate and many other parts of the anatomy show that it is a true reptile, probably more nearly allied to the Cotylosaurs of the Permian of Texas than to any other group. The uniform teeth indicate that the animal was a herbivore, which probably cropped the vegetation that grew on the banks of the Karroo lakes and marshes. Its movements must have been slow and deliberate like those of a tortoise, and the structure of its limb girdles seems to indicate that it walked with its body well off the ground. It is particularly interesting as being the first known animal that gave up crawling and took to walking, and there is reason to believe that it was a similar change of habit in some early reptile that started the line of evolution that gave rise to the mammals.

With *Pareiasaurus* was associated a somewhat larger but allied form called *Tapinocephalus.* Unfortunately little is known of it. Better known is a gigantic carnivorous reptile called *Titanosuchus*, which most probably preyed on the huge unwieldy Pareiasaurians. It probably stood about five feet high and was possibly over twelve feet in length. The skull was provided with large incisors and long powerful canine teeth. A smaller closely allied form is called *Delphinognathus*.

[NOTE.—Both *Tapinocephalus* and *Gorgonops* have been found to be Dinocephalians. *G. M.*, p. 401, 1909.]

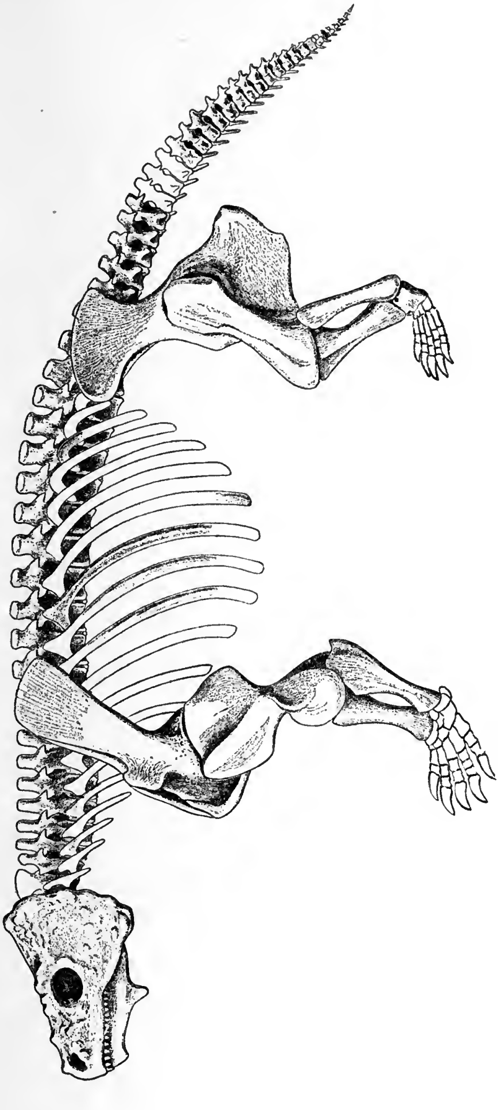


Fig. 16.—Skeleton of *Pareiasaurus serridens* (Owen), restored. The length of the animal was about 8½ feet.

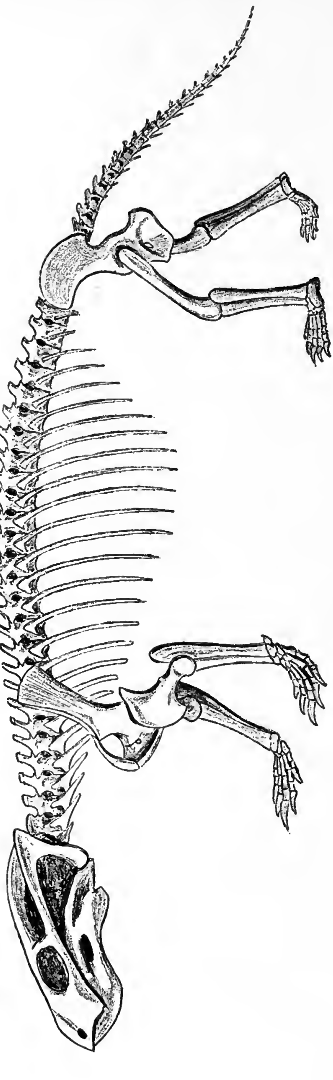


Fig. 17.—Skeleton of *Oudenodon trigoniceps* (Broom), restored.

This is one of the smaller known species of *Oudenodon*. The larger species are somewhat more heavily built. In the restoration the tail is partly hypothetical. No specimen of any species of *Oudenodon* is known in which the tail is preserved, but one species of *Dicynodon* is known to have a short slender tail. The length of the animal was about 14 inches.

Contemporaneously with these large animals, there were many small forms both herbivorous and carnivorous. The herbivores belong to a group of reptiles called Anomodonts, which form a much more important element in the later faunas. *Dicynodon*, which is the best known type, is represented in these later beds by a large number of species, and continued almost unchanged from this early period to near the close of the Karroo epoch. Some species are not much larger than a rat, others probably stood three feet high. The larger sorts were heavily-built animals which in general appearance must have looked like small hippotami. The head, however, was remarkable for having a large horny beak like that of a tortoise, with the addition of two large tusks in the upper jaw. With the exception of the peculiar appearance of the head, the animal must have been singularly mammal-like in build. Each foot had five toes, with the same number of joints as in mammals, and provided with large flat claws. *Oudenodon* was a closely allied form which differed mainly in having no tusks.

The carnivorous reptiles were even more mammal-like than the Anomodonts. One form, in fact, only known by the limb bones, was actually described as a mammal, and for some years believed by everyone to be so. They belong to a reptilian order called Therocephalia, the skull of which has a marked superficial resemblance to that of mammals. The teeth are divided into incisors, canines and molars, but frequently there are more than one pair of eye-teeth in each jaw and the temporal arch is formed on quite the mammalian pattern. The skull, however, differs from the mammalian in having the roof of the mouth open as in lizards, in having only one occipital condyle, and in having a complex lower jaw hinging on a quadrate bone. A large number of genera and species are now known, some probably smaller than a rat, others perhaps as large as a lion. Though the structure of the skull is well known, our knowledge of the rest of the skeleton is rather imperfect.

In the same beds occurs a remarkable Labyrinthodont genus *Rhinesuchus*, which is characterised by having large numbers of very minute teeth on the bones of the roof of the mouth.

In the Permian beds along the Dwina in North Russia a fossil fauna is met with remarkably like that of the Lower Karroo beds. *Pareiasaurus*, *Dicynodon* and *Oudenodon* are found associated with a large carnivorous reptile called *Inostranzewia* closely allied to the South African genus *Scymnosaurus*, and a species of *Rhinestoma* appears to occur in the Permian of Germany.

At Victoria West there occur one or two small reptiles which were possibly contemporaneous with *Pareiasaurus*. Of these the most interesting is a small animal little bigger than a rat and with a very long tail and which has been named *Galechirus*. Though essentially a Therocephalian it differs from all other known genera in having no coronoid process to the lower jaw, in having no distinct canines, and in possessing abdominal ribs. In those characters it agrees with the Rhynchocephalians, and thus seems to throw light on the origin of the phylum of mammal-like reptiles. Two other small reptiles, possibly semi-aquatic, are known from the same beds. These are *Heleophilus* and *Heleosaurus*. Both have long pointed skulls like *Mesosaurus*, but they must have been much less typically aquatic forms.

Above the *Pareiasaurus* horizon we come to a fauna much resembling the lower, but characterised by the absence of the gigantic herbivorous and carnivorous forms and by the great abundance and variety of Anomodonts. *Dicynodon* and *Oudenodon* are the commonest genera, most of the forms being of sizes varying from that of very young pigs to that of large boars. Many allied forms are met with which have in addition to the horny beak numerous small molar teeth. These form the group called Endothiodonts. The best known type, *Endothiodon bathystoma*, was an animal which stood about two feet high, and had an enormous head with a powerful beak; another Endothiodont was smaller than a guinea-pig.

Therocephalians are met with but are not so common as in the lower beds, and they appear to belong to a slightly higher type. *Cynodraco*, one of the best known, was an animal larger and more powerful than a wolf. *Scymnosaurus* was probably as large as a tiger, but some others were probably not larger than a cat. No very large animals appear to have lived in South Africa at this time, but a peculiar type of Pareiasaurian called *Propappus* survived. It is closely allied to *Pareiasaurus* but only about two-thirds the size, and it is remarkable for having had the whole back covered with bony plates somewhat after the manner of the crocodile.

Immediately above what may be called the Endothiodont zone is a series of beds characterised by the presence of a remarkable type of Anomodont called *Kistecephalus*.

This is a small form probably not much larger than a guinea-pig with a broad box-like head. It is very imperfectly known. With it apparently are a number of Therocephalians of a somewhat higher type than those met with in the lower beds. One genus, *Scaloposaurus* was probably as small as a rat. The other known genera are more comparable in size to dogs of various breeds.

Above this last formation occurs a large series of beds characterised by the remarkable scarcity of land forms and the frequency of an aquatic Anomodont called *Lystrosaurus* (=Ptychognathus, Ow.). This may be looked upon as a Dicynodont reptile which has become modified to suit a life mainly aquatic. The skull is so bent and developed that the large eyes are situated near the top of the head and the nostrils are also high up. This was to enable the animal when lying floating to breathe and to look about without moving or exposing much of its head or body. Some such modification is met with in almost all mammals or reptiles that became aquatic in habit. The limbs are short and the joints imperfectly ossified. Though *Lystrosaurus* probably spent most of its time in the water, it no doubt frequently came on to the land, on which it waddled perhaps as satisfactorily as a seal.

Succeeding the beds with *Lystrosaurus* are a series in which so far as is known only land forms occur. Of these the most noteworthy is *Procolophon.* This is a lizard-like reptile about eighteen inches in length with a broad triangular head. There is a little difference of opinion as to its affinities, but it is agreed by all to be one of the most primitive reptiles known. The skull has the temporal region roofed, acrodont teeth on the jaws, and small teeth on the prevomers. The shoulder girdle has a large precoracoid, and the number of joints in the digits are 2, 3, 4, 5, 3-4. Abdominal ribs are present. Another very interesting reptile called *Proterosuchus* is only known by an imperfect skull. The head is long and pointed and nearly a foot in length.

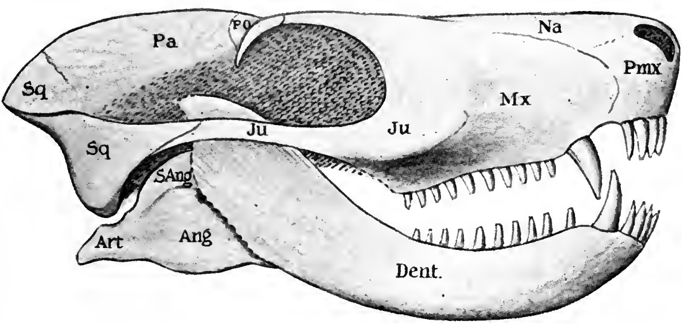


FIG. 18.—Skull of *Bauria Cynops*, Broom. Length of skull about 5½ in.

The structure of the palate shows that it is allied to the Rhynchocephalians, but it seems to be specialised along the line which gave rise to the primitive crocodiles and Dinosaurs. Still another interesting genus found in the same formation is a small true lizard called *Paliguana*. It is only known by the skull which is almost perfect and shows clearly that the quadrate was large and free as in modern lizards. This is the oldest known lizard and the only one at present known from Triassic beds though they have long been known from the Jurassic.

In the succeeding beds, which are the highest of the

Beaufort series, there is an extensive and fairly well-known fauna characterised mainly by the relative abundance of Cynodont reptiles. The Cynodonts formerly were not clearly distinguished from the Therocephalians, the two groups being both included in the order Theriodontia. There is little doubt that the Cynodonts are descended from Therocephalian ancestors, and one genus (*Bauria*) is known which to some extent forms a connecting link, but the two groups can be readily distinguished. The Therocephalians, as has been pointed out, have an open palate and a single occipital condyle, and are exclusively confined to Permian beds. The Cynodonts, on the other hand, are much more mammal-like. The palate is formed as in mammals by secondary plates from the maxillary and palatine bones and the occiput had two condyles. The quadrate is very small, and the articular, angular and surangular bones of the lower jaw also small. The dentary forms almost the whole of the jaw and almost articulates with the small quadrate. The molar teeth are in some forms cusped like the middle premolars of the dog; in other types they have flattened tops with usually two large cusps and numerous small ones. The general arrangement of the bones of the head is strikingly like that of the lower mammals, such as the polyprotodont marsupials. The shoulder girdle is not unlike that of the Anomodonts, but there is apparently no cleithrum. The carpus has still two centralia, but the radial one is very minute. The pelvis resembles the mammalian type and differs from that of all other reptiles in having an expanded anteriorly directed ilium, and a large obturator foramen.

The best known Cynodonts are *Cynognathus*, a large carnivorous animal as large as a tiger, but with short limbs; *Gomphognathus*, possibly a carrion-eating form about the size of a large dog; *Diademodon*, *Trirachodon*, and *Microgomphodon*, smaller forms with flat-topped molars; and *Sesamodon* and *Melinodon*, comparatively small reptiles with molar teeth which show signs of grinding, and apparently pointing to a loose articulation of the jaw. *Bauria* is a remarkable type which though undoubtedly a Cynodont, shows many affinities with the Therocephalians, and is thus a most important link in the line of mammalian descent. Besides the Cynodonts there are representatives of many other reptilian orders. *Erythrosuchus* is a huge, somewhat crocodile-like animal probably rather remotely connected with *Belodon* of Europe. Large species of *Dicynodon* and *Oudenodon* still linger on. The Rhynchocephalia are represented by *Palacrodon*, and the Gnathodontia by a remarkably interesting little reptile called *Howesia*. This latter shows affinities with *Hyperodapedon* and *Rhynchosaurus* of Europe. There are a number of different Labyrinthodonts. Portions of the skull of a carnivorous Dinosaur are believed to have come from beds which belong to the Cynodont horizon.

In the Stormberg beds reptilian remains are not common. Of those that have been discovered the majority belong to Dinosaurs. *Massospondylus*, a long-necked carnivorous genus, is the best known. A small carnivorous form has been named *Hortalotarsus*, but it seems to be identical with the European genus *Thecodontosaurus*. *Euskelesaurus* is a gigantic Dinosaur which

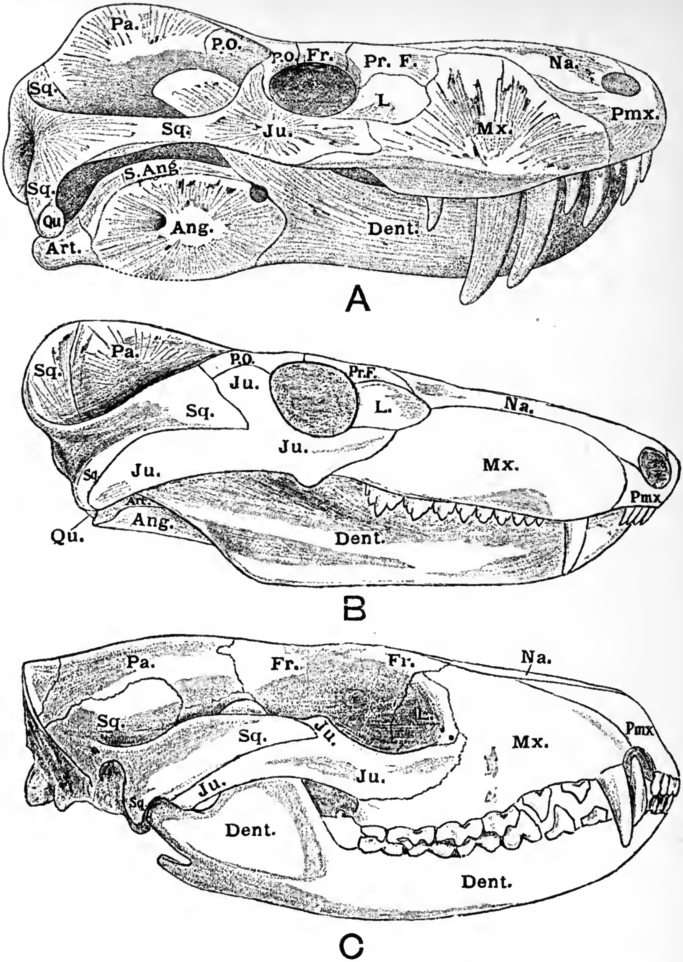


Fig. 19.—A. Skull of a Therocephalian, *Lycosuchus vanderrieti;* length of skull about 9½ inches. B. Skull of a Theriodont, *Cynognathus platyceps;* length of skull about 9 inches. C. Skull of a Mammal, *Dasyurus maculatus;* length of skull about 4 inches.

Ang., Angular; Art., Articular; Dent., Dentary; Fr., Frontal; Ju., Jugal; L., Lacrymal; Mx., Maxilla; Na., Nasal; Pa., Parietal; Pmx., Pre-maxilla; P.O., Postorbital; Pr. F., Pre-frontal; Qu., Quadrate; S. Ang., Surangular; Sq., Squamosal.

In no existing mammal are the nostrils separated by bone as in the Theriodonts, but in the early stages of development of the egg-laying mammals of Australia the pre-maxillaries are found with ascending median processes very similar to those of fossil forms.

is very imperfectly known. Perhaps the most interesting Stormberg fossil is the genus *Notochampsa.* This is a small narrow-snouted crocodile about two feet in length with rather long slender legs. The back is protected by two rows of large scutes. Though apparently a land animal in the main, its nearest affinity is with the European Liassic genus *Pelagosaurus.* Another very interesting animal which is believed to have been found in Stormberg beds is *Tritylodon.* This was an animal probably about the size of a fox-terrier, and is remarkable in having a row of molars and premolars formed by a series of pyramidal cusps arranged in three series, and in front a pair of large incisors. Owen described the form as a mammal, an opinion which has been supported by Cope and the writer. Seeley, however, believed the form to be a reptile.

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CHAPTER IX.

THE INTRUSIVE DOLERITES AND ALLIED ROCKS.

THE dark-coloured heavy rock, blue-black when freshly broken, and red, brown, black or yellow on weathered surfaces, that occupies such great tracts of country in Central Cape Colony, is popularly known by the name of "yzer-klip" or ironstone to the people who live near it. It probably got the name from the property it has of ringing like a piece of metal when struck.

The mineral composition shows that the rock belongs to the basic group of igneous rocks, and may be termed a dolerite. In this book, as in the Reports of the Geological Commission, this name is used in the sense adopted by Allport[1] and Teall,[2] including rocks composed chiefly of plagioclase and augite. The composition of the South African rocks varies considerably, and in very many localities rocks with obviously different compositions can be seen to belong to one and the same mass. The intrusions, however, as a whole can conveniently be termed dolerites.

The dolerites have all consolidated at some distance below the surface of the earth and can be seen only on the removal of the overlying rocks by denudation.

[1] *Q. J. G. S.*, xxx., p. 529. [2] *British Petrography*, ch. vii.

Among the hundreds of dolerite sheets that have been examined, none has been found to have the characters of a lava-flow; on the other hand, there is usually conclusive evidence in the hardening of the overlying rocks, and in the sheet breaking through to a higher or lower horizon, that the rock is intrusive, *i.e.*, that it reached its present position in a molten state after the surrounding sedimentary rocks had been deposited.

The commonest modes of occurrence of the dolerites are dykes and sheets or sills. The former are extremely abundant in the Colony and are remarkably uniform in width when their lengths are considered. The majority extend in more or less straight lines for many miles; sometimes they form curved or sinuous outcrops. In the Eastern Province a large proportion of the dykes trend either north-east or north-west.

Dolerite sheets are more noticeable in the Colony than any other form of intrusion; they are commonly connected with dykes which in some cases may be regarded as the channels through which the rock composing the sheets flowed.

In the Transkei there are dome-like masses of dolerite which resemble in their habit the intrusions known as laccolites. The arching up of the overlying beds characteristic of laccolites has not been observed, and it is probable that many of these apparent laccolites may really be curved sheets of dolerite.

It was stated in the Introduction that the dolerite intrusions are practically limited to that part of the Colony which was not seriously affected by the earth-movements that took place subsequently to the deposition of the Ecca beds. The position of their approximate southern limit is shown in the large coloured map.

In the west of the Ceres Karroo a nearly straight dyke about thirteen miles long and 100 feet wide runs north and south through Beukes Fontein, traversing the Dwyka conglomerate where that formation dips somewhat steeply to the east. This dyke dies out at each end and gives off no sheets. In the valley of the Brandewyn's River there are two dykes traversing the Bokkeveld and Table Mountain series in an area where these beds are slightly folded, and in the neighbourhood of Groen River and the Bokkeveld Mountain escarpment there are also two dykes breaking through beds belonging to the Cape system, but the beds have there been only very slightly disturbed.

No dolerite intrusions have been met with in the great folded belt between the Clanwilliam Mountains and the Gualana River. We have to go to the Cape Peninsula and to Pondoland, where the Table Mountain series lies almost horizontally, before we again come across dolerite in the Cape system. These occurrences are in the form of narrow dykes in the Peninsula and a thick sheet in Pondoland.

The northern limit of the Karroo dolerites is not yet known, for rocks of this type have been found as far north at least as Mafeking and near Rietfontein on the German border.

It is important to note that sheets are abundant in the Karroo system, but that wherever the latter have been removed by denudation, the intrusions in the Pre-Karroo rocks almost invariably form narrow dykes.

These dykes then must be regarded as the channels through which the rock composing the sheets flowed. The hard Pre-Karroo rocks must have been rather resistant to the invading magma, but the soft and evenly bedded Karroo sandstone and shales could be split up very readily, and the molten material was able to form thick sheets spreading underground over enormous areas.

The lowest sheet in Calvinia, for instance, certainly extends over an area of 3,000 square miles and probably a third more;[1] the lowest sheet north of Hopetown must have been continuous over at least 5,000 square miles without reckoning the area it occupied in the adjoining part of the Orange River Colony.[2]

A considerable number of dolerite dykes penetrate the Ibiquas series in the west of Calvinia, while a few are found in the Karroo beds of the Tanqua Valley, but the main area of the intrusions commences to the north of the Tanqua River.

In the Dwyka series between the Langebergen (Calvinia) and the Tanqua Valley there is a very extensive sheet which stretches, with a few breaks in the northern part of the outcrop, for rather over 100 miles; it is at places 300 feet thick. This sheet, and indeed all those in the western part of the Colony, tend to rise towards the south-east and they traverse higher and higher beds in the same direction. The lowest sheet first appears near the base of the Dwyka conglomerate north of the Oorlog's Kloof River, but at the base of Potkly's Berg East it is in the lower part of the Ecca

[1] *G. C.*, v., p. 50. [2] *G. C.*, xi., p. 124.

beds, having passed diagonally through a thickness of about 1,000 feet of strata in the course of sixty miles. The lowest sheet forms the foothills of the Roggeveld; outliers of it cap the Guap Mountain and Klip Rug Kop. An offshoot from the lowest sheet runs along the foot of the Roggeveld escarpment as far as the Rhenoster River, a distance of fifty miles; a second offshoot, at a higher level, follows the first one for about the same distance. A fourth sheet is connected with the third at Roode Fontein on the edge of the Roggeveld, and in addition to forming the edge of the escarpment for many miles to the south of that place, covers a wide extent of country to the north round Kreits Berg (Zand Kop), Roep-mij-niet and Hantam, as well as a great tract to the east.

There appears to be no direct connection of the Roggeveld sheets with those to the north-east in the vicinity of Sutherland. The latter are the continuations of a sheet which forms the summit of the western Nieuweveld, where it drops gradually to the level of the northern part of the Gouph; it has thus been traced between points of 100 miles apart.

East of the Tafel Berg, that fine flat-topped mountain with such gracefully shaped slopes below the 400 foot kranz of columnar dolerite, which can be seen together with its neighbour, Spitz Kop, from the railway beyond Prince Albert Road, the Nieuweveld summits are formed by outliers of sheets that occupy wide stretches of country behind the escarpment (Plate XVI.). Some of the sheets appear as continuous outcrops, usually in the form of cliffs 100 to 400 feet high, for about twenty

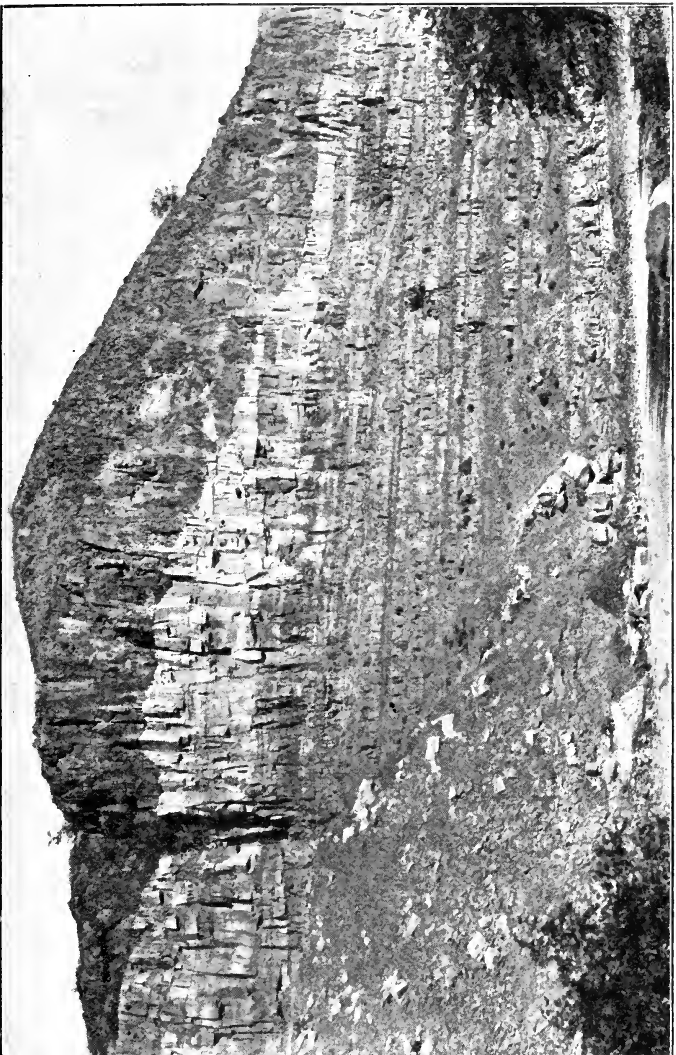


PLATE XVI.—A dolerite sheet at Paalhuis under the Nieuweveld escarpment. The dolerite is the dark rock at the top of the cliff; it cuts through the lighter coloured sandstones and shales (Beaufort beds) at an angle to the bedding.

miles along the edge of the escarpment, the highest point of which is the peak called Bulthouder's Bank, 6,270 feet above sea level and 3,500 feet above the town of Beaufort West, which lies about seven miles to the south-east.[1]

The Rooi Hoogte sheet, which is inclined northwards at a moderate angle, fronts the Great Karroo for nearly fifty miles and forms the southernmost of the dolerites for a distance of over seventy miles. It may have extended some way farther south than its present outcrops, but as there are no other dykes to the south, *i.e.*, no channel whence further sheets could have been supplied, and as there are no outliers of dolerite in that direction, we must regard the present outcrop of the Rooi Hoogte sheet as near the former southern limit of the intrusions.

The exact position of the southern edge of the dolerite country is not known east of Beaufort West, but the boundary runs between Aberdeen and Graaff Reinet, and follows, roughly speaking, the line of railway from Cookhouse to East London. Beyond East London the dolerites appear in great force throughout the whole of the Transkei and they are continued right through Natal.

North-west of the Nieuweveld there are numerous dolerite-capped hills, *e.g.*, the Karree Bergen, Slang Bergen, Tulbagh Mountains, Kat Kop hills, and the hills south of Williston (Amandelboom).

[1] A detailed description and map of the sheets and dykes of the eastern Nieuweveld will be found in *G. C.*, i., pp. 15-26; of the Roggeveld in *G. C.*, v., pp. 50-52, and viii., pp. 36-43.

A number of these hills possess three horizontal sheets of dolerite, the uppermost of which alone makes any marked feature, the lower ones usually weathering at the same or even at a greater rate than the sediments above and below them. Such examples are Beyers Berg and Aasvogel Kop (Victoria West) (Plate XVII.) and the Rhenoster Berg (De Aar).

From Fraserburg to the Stormberg conical mountains with flat tops of dolerite or with pinnacles, the remnants of former table-shaped summits, are frequently met with. Two particularly good instances are Theebus ("Tea-caddy") and Coffeebus ("Coffee-caddy"), between Rosmead and Steynsburg, while the "Three Sisters" at the railway station of that name are well known.

There are some very considerable ranges of mountains that run more or less parallel to the main watershed in the Eastern Province and divide the country south of that watershed into two parts, a northern (Middelburg, Cradock, Tarka, Queenstown), drained by the main branch of the Great Fish River and the Kei; and a southern part (Graaff Reinet, Somerset East, Bedford, King William's Town, etc.), drained by the Sunday's River, tributaries of the Great Fish, Kei, Keiskamma and Buffalo Rivers. These mountains branch from the main watershed at the Compass Berg (8,208 feet); they are called the Sneeuwbergen, Tandjes Berg, Bank Berg, Winterbergen, and Amatolas in different parts of their course. They all appear to owe their existence to the presence of thick inclined sheets of dolerite that have protected the sedimentary rocks from destruction. There

Plate XVII.—Aasvogel Kop, near Vosburg, north of Victoria West.

can be no doubt that they connect the well-known intrusions of Beaufort West with those of the native territories.

In Molteno, Queenstown, Glen Grey, Xalanga and

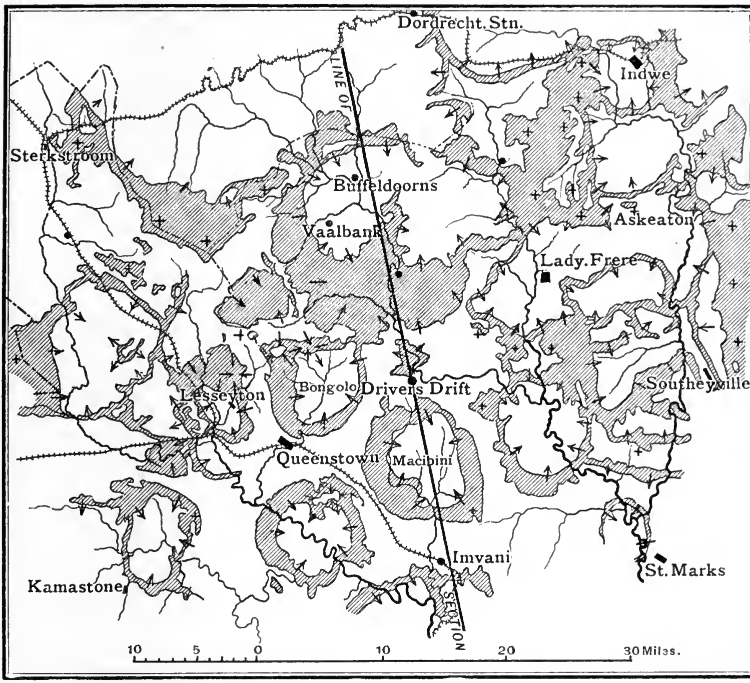


FIG. 20.—Showing the undulations of the Glen Grey dolerite sheet. The arrows indicate the direction of dip of the sheet, the crosses the places where it is horizontal.

Elliot dolerites are extremely abundant, especially in the Molteno beds. A peculiar feature is the tendency for an intrusion to occur immediately above the Indwe sandstone. In this way we find that the sandstone in many cases forms the scarped edges of extensive dolerite plateaux; for example, between Indwe and Lady Frere, around Cala, and north of Engcobo. In Queenstown and Glen Grey a thick sheet of dolerite undulates in a most uncommon manner, and forms, owing to irregular denudation, domes and basins often of no small diameter. In the east and north the regularity of the intrusion is broken by numerous offshoots from the main mass, while towards the west the sheet is now discontinuous owing to extensive denudation. In Fig. 20 the ramifications of this sheet are indicated, the arrows showing the directions of dip of the intrusions; a section through the same area is given

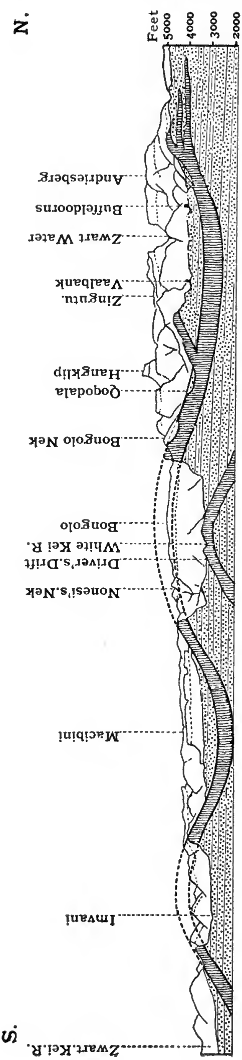


Fig. 21.—Section from Imvani to Buffeldoorns (looking west) showing the undulations of the Glen Grey dolerite sheet. Length of section 45 miles. This, taken from south to north, shows the Imvani dome and in the distance the exterior of the basin traversed by the Zwart Kei and Klaas Smit's Rivers. Then comes the Macibini basin, the denuded dome at Driver's Drift, and the exterior of the Bongolo basin. Further north comes the Qoqodala and Buffeldoorns' basins, with the dolerite crowned masses of Hangklip, the Zingutu, and Andriesberg in the distance. The foothills at Vaalbank and Buffeldoorns are formed by the Glen Grey sheet rising out of the valley and capping the hills beyond. The gap at Zwart Water represents a denuded dome.

in Fig. 21. As an example of one of the basin-shaped valleys produced by the denudation of this sheet, the Bongolo Valley, close to Queenstown, may be described.

It is about eight miles in diameter and hemmed in by a nearly circular ridge of dolerite; the drainage passes through a narrow gap in the south side of the ring. Seen from the outside the Bongolo basin appears as a ridge from 600 to 1,500 feet in height made of nearly horizontal sandstones and shales crowned by a steep palisade of rudely columnar dolerite. In the interior the rim of the basin is formed by a smooth slope of dolerite with an inclination of from 15 to 45 degrees; the igneous rock dips below the centre of the basin which is occupied by sandstones and shales. The general appearance of one of these basins is very strikingly like that of a recent volcanic crater.

The variation in the level of the Glen Grey sheet, as it is called, is often very considerable, even within a very short distance; for example, between Hangklip and Lesseyton, a distance of not more than seven miles, the drop is over 3,500 feet.

The intrusive sills have often produced a certain amount of faulting of the sedimentary rocks; the amount of the displacement in a few cases is as much as 400 feet.

The sheets are in many cases over 500 feet thick, but the Andriesberg in the south-west corner of Wodehouse and the Wildschuts Berg on the western border of Queenstown are crowned with horizontal masses of dolerite 1,500 and 2,000 feet thick respectively. The inclined portions of the sheets are, as a rule, thinner than the horizontal portions, and this is more pronounced as the inclination increases. There is also much variation in thickness of the dolerite sills in Kentani, the only area which has been mapped in detail along the south-east coast of the Colony.[1]

The Manubi sheet crops out on the right bank of the

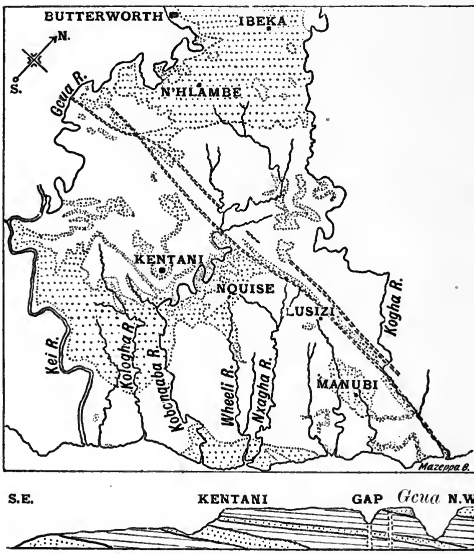


Fig. 22.—Map of Kentani showing the distribution of dolerite sheets and "gap" dykes. The area left blank between the Kei and Kogha river is made of sandstones and shales of the Karroo formation. Scale 1 in. to 10·6 miles. The vertical scale of the section is much exaggerated, $\frac{1}{6}$ in. to 1,000 feet. The name Manubi is written across the Manubi sheet. The trading station of that name is to the east.

Kogha, where it is 500 feet thick; it thins out rapidly to the west and is represented by thin outliers north and south of the Kabakazi Valley. North of Gqunqi it is cut

[1] *G. C.*, vi.

into by the stream to a depth of 300 feet, yet the lower surface is not exposed; it thins out in this direction very rapidly and disappears.

The upper half of the Kologha Valley lies in an extensive sheet which is continued across the Kei in the Komgha Division. The cliffs and slopes on the left bank of the Kei for a distance of four miles rise some 1,200 feet above the river, and two-thirds of the vertical height are composed of the dolerite of the Kologha sheet. On Inver Gcua the sill dips northwards across the sedimentary rocks, while to the east it gives off thin sheets.

The thickness of the intrusion varies greatly; on the Kei it is as much as 900 feet thick near Mimosa Dale, where both top and bottom are seen in the cliffs. On the Kobonqaba River it is at least 500 feet thick, but about five miles to the north-east it thins out completely.

In Pondoland and East Griqualand there are some very large masses of dolerite, much thicker in proportion to their area than any of the sheets hitherto mentioned. The Tsala hills near Lusikisiki are small examples of these masses, and larger ones are N'Tabankulu, Insizwa, Mount Ayliff, Mount Currie, and the Ingeli Mountain. These seem to be thick lenticular or cake-shaded bodies of rock, but their structure is not known in detail. The sedimentary rocks near them do not appear to be disturbed appreciably.

In the northern part of Cape Colony the dolerites are still abundant, but the country is much flatter and they do not give rise to such great ridges as farther south. The dolerite outliers in Kimberley, Barkly West, Her-

Plate XVIII.—The falls of the Tsitsa River in East Griqualand. The river falls about 370 feet over a dolerite sill some 250 feet thick; the lower part of the cliff is made of hardened shale and sandstone.

bert, Hopetown, Britstown and Carnarvon, are apparently portions of a single sheet which has been intruded in the Dwyka series at a horizon very close to its upper limit. Those peculiar ring-shaped intrusions described from Queenstown are represented in the north also. De Aar is situated just outside one of these, the railway to Prieska passing right across it; another one occurs at Deelfontein; a third is at Ercildoune, close to Britstown, and is interesting because a pan is found occupying the centre of the depression.

As a rule the dolerites are remarkably uniform in composition; a number of analyses were made by Prof. Cohen,[1] of which the following may be taken as typical:—

Silica, 52·7; alumina, 11·4; ferric oxide, 9·0; ferrous oxide, 3·7; lime, 11·6; magnesia, 7·4; potash, 0·7; soda, 2·3; water, 1·4; total, 100·2. The average specific gravity of the dolerite is very nearly 3·0.

The constituents are plagioclase felspar, augite, olivine, and magnetite, in the relative order of their abundance; but olivine is not infrequently absent. In addition, biotite may be present and sometimes original hornblende, either independently or in close connection with the augite. The pyroxene is in some varieties more or less altered to diallage, while the conversion of the olivine to greenish serpentine is a common enough feature.

In the more acid types quartz and occasionally orthoclase felspar are present, often in the form of micropegmatite.

[1] E. Cohen, "Geognostisch-petrographische Skizzen aus Süd-Afrika," *N. J. für Min.*, etc., 1887, Beil., Bd. 5, p. 195.

As a rule the dolerites have a well-developed ophitic structure; the plagioclase crystals are to a greater or lesser extent enclosed by the augite, but near the edges of the intrusions the augite is granular or forms rather imperfect crystals.

In thin dykes and sheets the structure is distinctly porphyritic, crystals of olivine, augite and plagioclase being embedded in a fine-grained matrix of augite grains and very small plagioclase crystals, often with a considerable amount of brown glass. Occasionally an almost pure glass, tachylite, is found at the contact of a sheet or dyke with the surrounding rocks, or in the form of thin veins traversing the dolerite or more rarely the sedimentary rocks. Tachylite is a black substance with a glassy appearance; it looks not unlike bright bituminous coal, for which it has often been mistaken in this country. The greater specific gravity and hardness of the tachylite, however, distinguish it at once from coal, and of course it will not burn. Porphyritic crystals of augite and plagioclase may occur in the tachylite, and the glass is sometimes converted into an opaque stony material along joints.

Both the tachylite and the glassy dykes and sheets owe their peculiarities to rapid cooling. The thick sheets of dolerite naturally took a longer time in cooling than the smaller bodies of molten rock, and consequently the minerals were able to develop more thoroughly in them than in the latter, so the rock as we see it now is coarsely crystalline in the one case and finely crystalline or glassy in the other. The fact that the well-formed crystals of olivine are often abundant in the coarse dolerites and absent from the fine-grained and glassy rock, points to the conclusion that the molten rock which forms the latter has been squeezed out of a partly consolidated dolerite in which the large olivine crystals were retained by the partly formed plagioclase and augite.

In the Eastern Province there are certain basic intrusions which cut the dolerite sheets and dykes, as for example the two long parallel dykes which pass through the town of Lady Frere. These intrusions do not exhibit an ophitic structure, the rocks being usually porphyritic. In Victoria West and Carnarvon the same is also the case.

It is not uncommon to find more acid varieties of the dolerite, distinguished from the typical dolerite by their lighter colour, which is due to their containing a larger portion of quartz and potash felspar, less augite and no olivine. In some cases they pass insensibly into the normal basic rock; for example, in a sheet between Sterkstroom and Tarkastad. A section of the rock from this locality shows an intimate intergrowth of pale brownish augite, pale green hornblende, large crystals of plagioclase, much magnetite, and a very large amount of quartz usually forming a micropegmatitic intergrowth with felspar.

Generally, however, these acid varieties form veins or dykes which cut through the dolerite sheets, and in many cases the rocks can be termed granophyres. Notwithstanding this, there are strong reasons for believing that they are a late product of the same molten rock-magma that supplied the dolerites; the more basic portion represented by the dolerites was got rid of, and a part of the more siliceous residual matter was extruded after the dolerites had solidified. These acid dykes appear to be more abundant and larger in the Transkei than elsewhere.

On Plate XIX. is shown a thin dyke of light colour traversing a sheet on the shore near the Kobonqaba mouth, Kentani. The sheet itself is a rather coarse ophitic olivine-dolerite; a small amount of green hornblende is intergrown with the augite, and red biotite, magnetite, and apatite are present in fair quantities and quartz in very small amount; the olivine is partly converted into serpentine. The light-coloured dyke has no olivine or augite in it and very little hornblende; red mica is abundant; the plagioclase forms zoned crystals. In addition there is much orthoclase in the rock, intergrown with quartz to form micropegmatite. Apatite, magnetite, and zircon are found in the acid rock as well as in the dolerite.

Near Gqunqi there is a short dyke-like mass of granophyre about a mile long from north to south and several hundred yards wide; it is rather like the acid dykes of the Kobonqaba sheet. It traverses both the sedimentary rocks and the Manubi sheet.

A large mass of very acid rock later than the dolerite sheets forms a considerable part of Gonubie Hill in Komgha; it is a microgranite consisting of quartz, orthoclase, and black and white mica.

The east and west dykes that traverse the Kentani Division are very remarkable ones; they extend from the Kogha mouth to the Gcua River and can be followed

Plate XIX.—Dyke of granophyre (light-coloured) traversing a thick sheet of dolerite near mouth of Kobonqaba River, Kentani.

across the Kei into Cathcart (see Fig. 22). From a certain point on the road between the Kei bridge and Toleni, not far from the Eagle's Nest, a fine view can be obtained along the valleys weathered out along the course of the dykes; on the west a long line of valleys with low cols between each pair can be seen on either side of the Kei, and to the east a similar line of valleys stretches for many miles between slightly higher ground.

The dykes are made of a rather coarse rock composed of augite, hornblende, red mica, plagioclase, orthoclase (in micropegmatite) and quartz, with ilmenite, apatite and zircon as accessories. The rock can be called an augite-mica-diorite.

The coarse diorite weathers more readily than either the sedimentary rocks or the dolerite through which it passes, consequently the minor streams in its neighbourhood have worked their way along it rather than through the more resistant rocks, with the result that a series of valleys with low cols between each pair have been formed. These are called "gap-valleys"[1] from the local name of "Transkei Gap" given to the whole series of valleys by the early surveyors and residents in the Transkei.

There are two of these gap-dykes in Kentani, lying parallel and about a mile apart, but they cross, or join and separate, in the N'Debe Valley. The northern dyke is not continuous on the surface between the Gentuli River and Cat's Pass, but the separate parts are very probably connected underground. The longest valley

[1] The gap-valleys of the Transkei have been described in detail in the *T. S. A. P. S.*, vol. xiv., p. 66, 1903.

along the southern dyke is that of the Kabakazi and the lower part of the Kogha, in all about ten miles long. The width of the dykes is at the most 400 feet.

The intrusion of these dykes was certainly later than that of the dolerites, for they cut through the latter. In its nature and composition the augite-mica-diorite forming them is intermediate between the ordinary olivine-dolerite and the granophyres mentioned previously. None of the minerals or structures in the diorites are entirely foreign to the dolerites, and the diorites contain much less quartz and micropegmatite than the granophyres. Olivine is the only constituent of the dolerites that is absent from the diorites and granophyres.

This bears out the opinion that all these rocks can be regarded as having been derived from the same molten rock-magma; it is not assuming too much to suppose that the whole of the dolerite sheets and dykes of the Karroo region belong to one period of igneous activity.

While dykes and sheets are abundant in the Molteno beds in the Red beds they are not so numerous, in the Cave sandstone sheets are almost absent, and in the volcanic beds the dolerites are, at least chiefly, represented by narrow vertical dykes. These dolerites which cut both the lavas and the tuff-filled pipes from which they once issued can be definitely traced to the large sheets of the lower-lying country. How much later than the Stormberg lavas they are is not quite clear. Although the dolerites differ somewhat from the Stormberg lavas, in containing biotite mica and sometimes brown hornblende, and in having a higher specific gravity, and although some of them were intruded subsequently to the eruption of the volcanic rocks, yet nevertheless there seems to be a very close connection between the two groups of rocks, indicating a common origin; the one consolidated below ground and the other at the surface.

It is difficult to form a satisfactory estimate of the thickness of rock cover at the time of the intrusion of any particular sheet, but a minimum estimate can be made in the case of some of the sheets under the Drakensberg in Elliot. The dykes here ascend to an altitude of about 8,000 feet above sea level, while sheets and dykes are exposed on the low ground not far away at an altitude of about 3,500 feet, *e.g.*, Lady Frere and Engcobo. The thickness of cover must have been at least 4,500 feet without reckoning the thickness of volcanic beds subsequently removed by denudation.

The question of the origin of the dolerite intrusions and the means whereby they were able to force their way between and through the sedimentary rocks is at present beyond our knowledge. During the Stormberg period there must have been an enormous mass of basic material lying at an unknown depth beneath the surface of the South African region ready to burst its bonds and rise towards the surface when favourable conditions prevailed. What these conditions were is at present a subject for speculation rather than for statement. It may be noted that the mountain building in the south and south-west had probably then reached or passed its maximum, and that the great forces exerted cannot but have influenced the fluid or potentially fluid rock-magma. The avoidance by the dolerites of those portions, which were being compressed and folded, together with the abundance of intrusions in the undisturbed portions, is very suggestive.

The age of the intrusions can be fixed with some probability. Boulders of dolerite are found in the Embotyi conglomerate of the Pondoland coast, probably of Upper Cretaceous age, while along the Buffalo River a small patch of Upper Cretaceous beds rests upon a sheet of dolerite. The Uitenhage conglomerates have hitherto been found only at a distance from dolerite outcrops, so the absence of boulders from these conglomerates throws no light on the matter. Seeing that the dolerites followed the Stormberg volcanics (Lower Jurassic) fairly closely and that an enormous amount of denudation must have taken place subsequently, but prior to Upper Cretaceous times, it appears most likely that the dolerites were intruded during the Jurassic Period.

At the contact of the dolerite sheets and dykes with the sedimentary rocks there is generally a noticeable hardening of the latter through a distance varying with the thickness or width of the intrusion. Shales and mudstones are changed to lydianite or hornstone, a dark hard flinty-looking rock which breaks with a conchoidal fracture; the typical hornstone is only a few inches in thickness, but sometimes the metamorphism extends over a considerably greater distance.

In a few cases the heat has been so intense that the sediment at the contact has been fused; the product so formed is a black vitreous material which under the microscope is found to be full of minute crystals of cordierite, tiny octahedra of magnetite and sometimes corroded grains of quartz.

In the case of sandstones the contact rock is hard and splintery, like a quartzite, the rock becoming harder by the cementing together of the constituent grains by quartz. Clear colourless felspar, probably orthoclase, has in a few cases developed, but the commonest contact mineral is epidote, occasionally accompanied by lime garnet (grossular). Epidote is a silicate of alumina and lime and is only formed in those sediments which were originally calcareous. The presence of amygdale-like bodies of epidote and quartz in the shales near dolerite is very characteristic and has been noted in many districts. Cavities with remarkably smooth surfaces, identical in appearance with the steam-holes in lavas, were formed probably by the conversion of the water held in the then soft sediments into steam, and these spaces were subsequently partially filled by the epidote and other minerals formed by heated water vapour acting on the constituents of the surrounding sediments. The epidote gives a green colour to the contents of these cavities. The calcareous concretions in the shales are sometimes converted into epidote, but the lime-silicate wollastonite has not been noticed as a contact mineral.

The action of dolerite upon carbonaceous shale and coal is very marked, and in the Stormberg district the seams have been destroyed over wide areas or else rendered unsaleable through intrusive dykes and sheets. The combined carbon and hydrogen of the coal have been partly or wholly removed and a semi-anthracite or anthracite produced. At the contact with the dolerite the coal is burnt and sometimes rendered columnar, while thin intrusions of the igneous rock are altered to the material known as "white-trap". The hydrocarbons produced by the distillation of coal and carbonaceous shale may in part enter the molten rock and be retained in it upon its solidification. It is therefore not unusual to find in a dolerite intrusion traversing carbonaceous shales, cavities or vesicles containing oil or tarry matter; the sediments at the contacts may also be impregnated with bituminous material.

The numerous petroleum "indications" in Central Cape Colony are almost without exception associated with dolerite intrusions and seem to be due to the destructive distillation of carbonaceous Karroo shales, notably the "White band" of the Dwyka series. It is therefore a matter of regret that so much capital and labour is being spent upon these indications, owing to the true nature of the occurrences not being realised.

A dolerite intrusion not infrequently produces a columnar structure in the adjoining sedimentary rock. A very marked example of this is shown in Plate XX., a view of the junction of a thick dolerite sheet with the Dwyka tillite on the farm Dwas Douw in the Doorn River Valley, Calvinia. The rough-looking rock in the upper part of the cliff is the dolerite, and the columnar rock forming a vertical face fifteen feet high is the tillite. The lower end of the columnar layer is sharply marked, and below it the tillite is the usual sandy mudstones containing numerous boulders of many varieties of rocks. The photograph was taken at too great a distance from the cliff to allow the boulders exposed on the joint faces to be seen. The joints that divide the

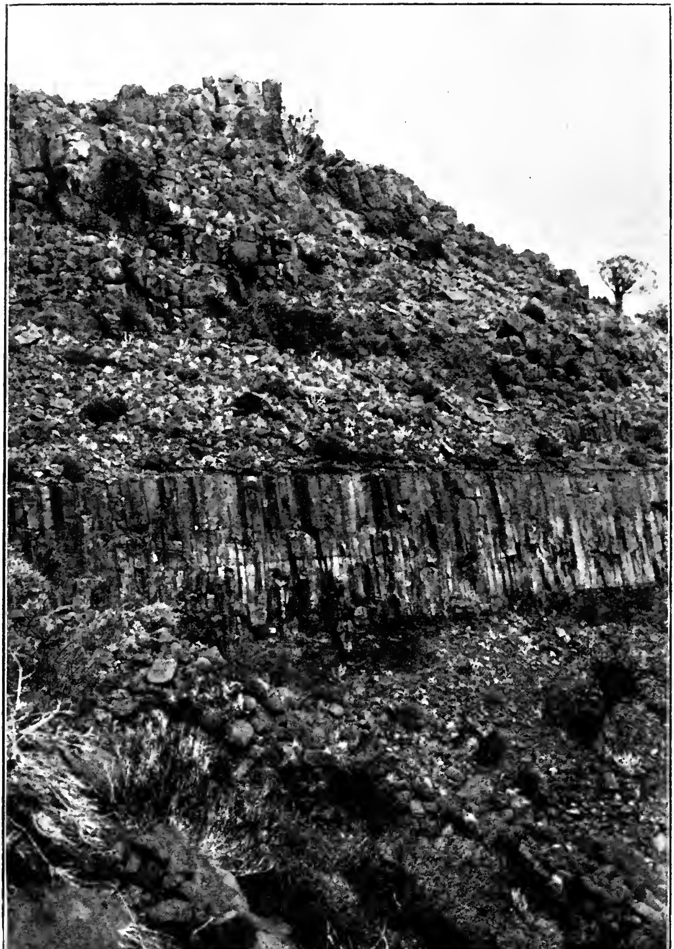


Plate XX.—Columnar structure in Dwyka tillite produced by the overlying sheet of dolerite. The slope below the columnar rock is unaltered tillite. The columns are 15 feet high. Dwas Douw, Calvinia.

tillite into regular columns traverse boulders and matrix alike without deviation.

The larger intrusive sheets of dolerite frequently show columnar structure. Many examples of this can be seen in the sheets which crown the Nieuweveld escarpment in Beaufort West. Other good examples are Tafel Berg (Beaufort West), Theebus near Steynsburg, and Donker Hoek's Berg near Sterkstroom.

Owing to the strong tendency to spheroidal weathering that is characteristic of the dolerite, the intrusions give rise to great piles of boulders. Thousands of square miles in the Upper Karroo are covered with boulders such as are seen in the foreground in Plate XXI., which is reproduced from a photograph of typical dolerite country behind the Nieuweveld escarpment. Not infrequently the dolerite decomposes to a coarse yellow-brown crumbly material which can be easily excavated. This is particularly the case wherever the rock forms wide flat tracts of country, as around Kimberley for example.

Occasionally portions of such a sheet weather much more slowly than the rest, and a peculiar type of scenery is produced in which masonry-like masses of jointed dolerite rise in mounds from a plain of rotten crumbly dolerite. This can well be seen at Pampoen Poort between Victoria West and Carnarvon. Wells and bore-holes in such decomposed dolerite usually yield good supplies of water.

The country occupied by the dolerite sheets is, as a rule, more fertile than that formed by the sedimentary rocks alone, for the dolerite contains valuable food

Plate XXI.—Surface formed by a dolerite sheet in the Fraserburg Division, near the road between Fraserburg and Williston. The hills in the distance are also of dolerite.

materials for plants which are set free during the slow decomposition of the rock by the action of the weather and the damp soil. It is only to the east of King William's Town in the country within fifty miles of the coast that full advantage can be taken of the valuable soils derived from the dolerite; the outcrops there are no longer marked by krantzes or definite ranges of kopjes, but large areas of that rock are covered with fairly deep soil, and unweathered lumps of dolerite are rarely met with in the soil itself. In the arid central and western districts the soil cannot accumulate rapidly enough to clothe the steep slopes, for it is not held together sufficiently by grass and other plants to resist the occasional heavy rains. In the place of the extensive, richly grass-covered plateaux of the east, we find extremely rocky ground sparsely dotted over with small bushes, and supporting grass only for short periods after rain.

The colour of the dolerite hills is usually dull red, but extraordinarily vivid crimson and yellow patches are often met with, and are due to a lichen growing on the weathered crust of the rock. The most exposed surfaces of dolerite boulders in the drier regions become coated with a very thin film of deep brown or black material, which has often a well-polished appearance. This thin coat seems to be chiefly composed of hydrated oxides of iron derived from the rock immediately beneath it. Dolerite, however, is not the only rock which behaves thus in the dry parts of the Colony.

The dolerites do not seem to contain valuable minerals in sufficient quantity. Copper pyrites accompanied by pyrrhotine and carrying a small amount of nickel has been discovered in Mount Ayliff, East Griqualand, near the contact of dolerite[1] and shales, while similarly occurring impregnations of copper minerals have been found in Cathcart, Queenstown, and a few other localities. Small amounts of galena occur in very narrow veins in the Roggeveld sheets. Prehnite is not uncommon in cavities and joints in the dolerites and sometimes carries a trace of gold. At Bekker's Kloof near Cradock there is a vein containing copper pyrites carrying several pennyweights of gold to the ton.

[1] The rock contains a rhombic pyroxene and can therefore be termed norite.

CHAPTER X.

THE CRETACEOUS SYSTEM.

The Cretaceous beds in Cape Colony are divided into three main groups, the Uitenhage, Pondoland, and Need's Camp series. The relative ages of these beds is determined by their fossils, and they correspond respectively to the Neocomian, Senonian, and perhaps Danian series of the Cretaceous system. The Uitenhage and Pondoland series have not been found in one and the same area, neither are the Pondoland and Need's Camp series known to occur together, but the Need's Camp beds rest unconformably upon the Uitenhage series in Alexandria.

While the Uitenhage series covers rather wide areas in the folded belt between the Karroo and the coast, resting unconformably upon rocks of various ages from the Malmesbury to the Ecca beds, the other two groups are only known from the coastal belt between the Sunday's River and Natal.

1. The Uitenhage Series.

In the typical area, the valleys of the rivers flowing into Algoa Bay, this series has been subdivided into the following groups :—[1]

[1] This classification is substantially that of the late Dr. W. G. Atherstone.

Sunday's River beds .	Clays, shales and sandy limestones with marine fossils.
Wood beds . . .	Yellow sands, shales and limestones with a few marine shells and numerous plants.
Enon beds . . .	Sandstones, marls and conglomerates.

THE ENON BEDS.

The Enon beds are found at the base of the series throughout the district, but the thickness and nature of the rocks differ very much within rather short distances. In the upper part of the Zwartkops River the Enon beds attain a very considerable thickness, as is also the case near Enon; but near Blue Cliff Station the conglomerate lying between the sandy and argillaceous rocks of the Uitenhage series, and the surface of the older rocks below, the Bokkeveld beds in this case, is at most only a few feet thick, and at places it is entirely absent.

The Enon beds are here taken to include the Zwartkops sandstone and variegated marls of Atherstone's classification,[1] for the conglomerates are so intimately connected with rocks agreeing with Atherstone's description of these two subdivisions that it is convenient to group the three together. There is indeed much reason to believe that the three subdivisions of the Uitenhage series are to be regarded more as three kinds of deposit formed under different circumstances, but at about the same time, than as successive groups of deposits. In any one spot, such for example as Wolve

[1] Atherstone, "The Geology of Uitenhage," *Eastern Province Monthly Magazine*, vol. i., pp. 518, 580, Grahamstown, 1857.

Kraal on the Sunday's River, the marine Sunday's River beds may be underlain by the Wood beds and those again by the Enon, but there is evidence that even in the Uitenhage area rocks like the Enon beds were formed during the deposition of some of the Sunday's River beds. On the hill west of the native location at Uitenhage there is a small thickness of grey shale and limestone, containing marine fossils, interbedded with red sands and gravels belonging to the Enon type, although to the east of Uitenhage these marine strata are not found interbedded with conglomerates or sands of the Enon type. The sands and pebble beds west of the native location at Uitenhage lie against a rather steeply inclined slope of sandstone and quartzite belonging to the Table Mountain series, evidently the shore during a certain stage of the deposition of these rocks. The sands and conglomerates are the deposits formed near the shore, or in most cases probably in steep-sided inlets, drowned valleys in fact, which bordered the sea in which the Sunday's River beds were laid down. The marine beds intercalated with the red beds near the location represent a period of extension or encroachment of the sea on the land-locked inlet in which the red beds were formed.

In the Uitenhage district, then, we find that the Enon beds cannot be regarded as merely the earlier deposits of the Uitenhage period. As far as our knowledge goes, they certainly were the earliest of these deposits, but their formation continued during the laying down of the marine clays and limestones of the Sunday's River beds along the shores of the sea in which the latter were deposited. In the country farther west there is corroborative evidence of this, as we shall see later.

Fragments of wood with a charred appearance, very different from the petrified wood in the Wood beds, occur frequently in the Enon beds, and up to the present time these are almost the only organic remains known from the typical Enon beds in the Uitenhage area.

At Enon, which is situated in a kloof under the Zuurbergen, the conglomerate forms high hills which are curiously carved into crags and caves by the action of the weather, the rocks being harder in some places than others. The conglomerate is white or red, but in this neighbourhood there is no general occurrence of a lower band of red rock and an upper layer of white as in Willowmore. From Enon the conglomerates have been followed eastwards to the Bushman's River; but the belt of ground occupied by them becomes narrower in that direction, for they are let down along the Zuurberg fault, the throw of which increases eastwards and brings in the clays and shales above the conglomerates. At Sand Flats a bore-hole sunk at a spot 1½ miles south of the fault penetrated 1,500 feet of sediments without reaching the conglomerate. From Enon eastwards the dip of the beds is southwards, away from the fault, at various angles up to 20°, but the dip decreases southwards. The south flank of Zuurberg west of Enon and east of Bushman's River has not yet been surveyed geologically, and the terminations of the fault and the remarkable volcanic rocks along it (see p. 366) are not known. The conglomerate in this area contains pebbles of quartzite and quartz up to eight inches in length embedded in a sparse sandy matrix so that they are often in contact with each other; they have often been indented or cracked by mutual pressure.

In the upper part of the Zwartkops Valley the conglomerates are very thick, over 1,000 feet, and the same is the case at Hankey in the Gamtoos Valley. They are overlain as a whole by the beds called Zwartkops sandstone and Variegated marls by Atherstone, but conglomerate bands are not infrequent in these higher beds. On the right bank of the Zwartkops River below Uitenhage the red clays are worked for brick and tile making. The thickness of conglomerate below these clays and sands is very slight to the south of Uitenhage, where the Humansdorp Road leaves the Zwartkops Valley, but the clays and sands contain thin beds of conglomerate. In the clay pits belonging to the Port Elizabeth Brick and Tile Company near Despatch Station bones belonging to a dinosaur, *Algoasaurus baini* (Broom), have been found.[1]

In the Bezuidenhout's River Valley from a short distance above Blue Cliff Station to a point some four miles above the railway bridge, the rocks lying below the Wood beds are well exposed at intervals along the river banks. They are reddish-yellow sands, red clays and thin sandstones, with occasional pebble beds. Conglomerates like those of Enon are entirely absent from this valley. Near the fortieth milestone on the railway between Uitenhage and Blue Cliff, greenish sandstones very like some that occur in the Bezuidenhout's Valley

[1] Broom, *G. M.*, 1904, p. 445.

lie against slates belonging to the Bokkeveld series, without the intervention of any conglomerate.

The Wood Beds.

The Wood beds are found overlying the Enon in the northern part of the area, and are especially well seen between Blue Cliff Station and the Witte River below Enon. The valley of the Bezuidenhout's River below Blue Cliff lies entirely in the Wood beds, and both above and below its confluence with the Sunday's River the rocks are well exposed in the bed of the latter river. The total thickness of the Wood beds in this locality may be as much as 1,000 feet. They consist of various sediments, sands, clays, hard limestones and sandstones, and well-laminated shales.

The base of the Wood beds in this valley is taken to be a loose yellow sandstone, seen in a cliff section above Blue Cliff Station. Farther down the valley many large pieces of tree-trunks, one of which is twenty-five feet in length, are preserved in a clayey sandstone. These are probably the trunks of conifers, but no leaves or other parts of the trees have been found with them. Some of the wood evidently lay for some time in the water, for the shells of a small boring mollusc, *Gastrochæna dominicalis*, are found in it in considerable numbers. The only other animal remains discovered in these sandstones are oyster shells, and some fragile fragments of large bones, too imperfect to be named. In some hard limestone bands intercalated with the upper part of the sandstones there are numbers of shells of *Unio uiten-*

hagensis. Curiously twisted stems, which may have belonged to a cycad, occur in the upper part of the sandstones, as well as stems of *Benstedtia*.

The chief interest of the Wood beds lies in the well-preserved leaves and other parts of plants that are preserved in the bluish-grey sandy mudstones, clays, and thin limestones between Paltje's Kraal (on Bezuidenhout's River) and the lower portion of the Witte River, including the bed of the Sunday's River near the Dunbrody Mission Station.[1] Some of these beds are crowded with the broad fronds of *Zamites*, a cycad of which several species have been found; they are accompanied by other cycads, conifers and ferns.[2]

The following is a list[3] of the plants hitherto obtained from these beds, those marked with an asterisk having been also found in the Gamtoos Valley:—

Ferns—

* *Onychiopsis mantelli*, Brongn.
Cladophlebis browniana, Dunk.
,, *denticulata*, Brongn., forma *atherstonei* (found also at Herbertsdale).
* *Sphenopteris fittoni*, Sew.
,, sp.
Tæniopteris, sp. (found also at Herbertsdale).
Osmundites kolbei, Sew. (found also at Herbertsdale).

[1] Dunbrody is the Geelhoutboom of the Divisional maps, a name which is used by Atherstone, Tate and other writers.

[2] All the plants mentioned in this chapter are named according to Prof. Seward's determinations published in *A. S. A. M.*, iv., pt. i., 1903, and in *G. M.*, 1907, p. 481. The specimen of *Phyllotheca whaitsi* described in the latter paper came from the Beaufort beds.

[3] Tate, R., *Q. J. G. S.*, xxiii., p. 139, 1867. Seward, A. C., *A. S. A. M.*, iv., pt. i., 1903; *G. M.*, p. 481, 1907.

Cycads—
* *Zamites recta*, Tate.
,, *morrisii*, Tate.
,, *africana*, Tate.
,, *rubidgei*, Tate.
Cycadolepis jenkinsiana, Tate.
Benstedtia, sp.
Carpolithes, sp.
Bucklandia, sp., *cf. anomala* (Stokes and Webb).

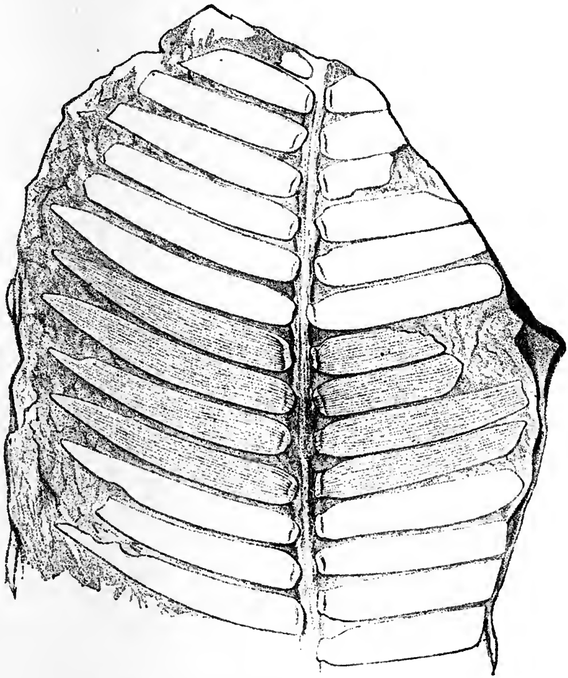
Conifers—
Araucarites rogersi, Sew.
* *Taxites*, sp.
Brachyphyllum, sp.
Conites, sp.
Coniferous wood.

The lowest fossiliferous beds seen on the Witte River contain *Onychiopsis mantelli*, but the beds containing coniferous wood and reptilian bones in the Bezuidenhout's River are probably lower than these. A section taken in an approximately north-east direction along the Bezuidenhout's and Witte Rivers from one side of the Uitenhage deposits to the other is by no means similar towards each end, owing to the much greater development of the conglomerates along the Zuurbergen.

The Sunday's River Beds.

The plant-bearing beds pass upwards into bluish rocks containing marine fossils, but the whole of the passage beds is not exposed along the Sunday's River; the lowest marine fossils above the Dunbrody plant beds are *Ostrea*, *Perna atherstoni*, *Mytilus uitenhagensis*, *Cyprina rugulosa*, *Psammobia atherstoni*, *Turbo atherstoni*, *T. rogersi*, *T. minutulus*, *Actæonina atherstoni*, *Pecten* *cottaldinus*, and *Gastrochæna dominicalis* in the fossil wood.

The Uitenhage beds in the Sunday's River Valley and adjoining country form a wide synclinal trough trending



Zamites recta. Two-thirds natural size.
FIG. 23.—Plant from the Uitenhage series (Wood beds) (from Seward).

nearly north-west, but its axis sinks to the south-east, so that higher and higher beds are met with in that direction. There is also undoubtedly a greater development of the marine beds (Sunday's River beds) as compared with the conglomerates and sands (Enon and

Wood beds) in the same direction, so that the sinking of the synclinal axis towards the south-east appears to be more than it really is, for the distribution of the different subdivisions of the series is the chief evidence

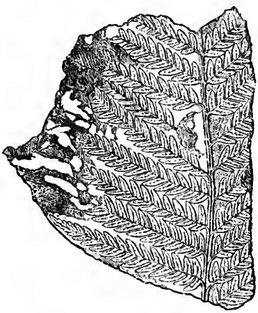
Onychiopsis mantelli. Half natural size.

FIG. 24.—Plant from the Uitenhage series (Wood beds) (from Seward).

of the nature of the fold into which the rocks have been thrown. The dips are generally low; on the left (or north-east) side of the Sunday's River they are towards the south-west, and on the right towards the north-east.

The typical marine Sunday's River beds are exposed in the cliffs on the banks of that river below Wolve Kraal, in the Zwartkops Valley below Uitenhage, near the Coega River, and at some other places such as the Grass Ridge east of the town of Uitenhage, the Bethelsdorp Salt Pan and the Zwartkops Salt Pan.

The whole area has not yet been worked out, but from the collections made up to the present time there seem to be no marked divisions of the marine beds, differing in their fossils. The lowest marine beds visible near the Zwartkops River are clays with badly preserved shells of *Nucula*, *Pecten*, *Actæonina atherstoni*, *Bochianites*, *Dentalium* and other marine mollusca; these beds are exposed in a clay-pit near the north end of the Rawson Bridge, the bridge over the Zwartkops River. Stow mentioned some clay beds near the Salt Vlei,



Cladophlebis browniana. Half natural size.

Fig. 25.—Plant from the Uitenhage series (Wood beds) (from Seward).

Port Elizabeth, containing *Zamites* and other plants associated with marine shells; these rocks probably belong to the upper part of the Wood beds, like those at Dunbrody, and may be older than the lowest marine clays in the Zwartkops Valley. The bulk of the marine beds consist of clays, sandy shales, inconstant sandstones, and limestones, usually bluish-grey when freshly exposed, but weathering with yellow and brown surfaces. The limestones are often crowded with shells, and some layers in the shales are composed almost entirely of the

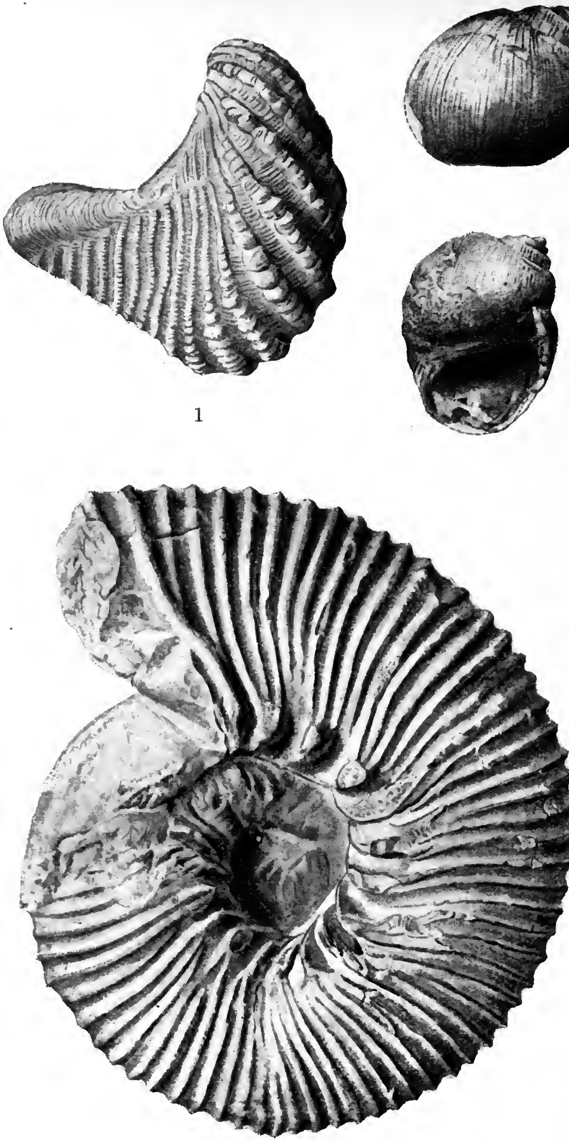


Fig. 26.—Fossils from the Sunday's River beds.
1. *Trigonia ventricosa*. 2. *Natica uitenhagensis*.
3. *Holcostephanus wilmanae*.

shells of *Exogyra imbricata*, and others consist largely of *Trigonia ventricosa* shells. Parts of the skeleton of a reptile related to *Plesiosaurus* have been obtained from the cliffs above Picnic Bush.

A bore-hole (by jumper drill) which is now being sunk near the mouth of the Zwartkops River near sea level, has reached a depth of 3,000 feet, and marine shells, some of which are like those from the Rawson Bridge clay-pit, were obtained at 2,300 feet. The fragments are of blue clays and sandy beds.

In the Sunday's River Valley the marine beds are exposed at intervals from near Dunbrody to the mouth of the river.[1] The beds on the Olifant's Kop cliff seem to be the highest in the valley, though from the lack of sufficient exposures it is difficult to ascertain the stratigraphical position of the beds on the left bank near Colchester relatively to those in the more continuous sections above Barkly Bridge. Several fossils certainly occur throughout the marine beds in this valley, though others, especially *Trigonia ventricosa*, have been found in the higher beds only. Of some of the most important fossils such as the various species of *Holcostephanus* only a few individuals have been found, and there are great opportunities for local collectors both in this valley and also in the Coega and Zwartkop Valleys.

In the outliers of the Uitenhage series to the west of the division of that name deposits similar to the Sunday's River beds are only known in the Knysna Estuary.

[1] An account of most of the sections is to be found in *G. C.*, x., and a list of accurately determined species from these and other localities in Kitchin's paper in *A. S. A. M.*, vol. vii., pp. 219-24.

In the Gamtoos Valley (Humansdorp) there are conglomerates and sandstones like those of Enon and the Zwartkops River. Along the left bank of the valley below the railway bridge, and also in the valley of the Loerie River, there are conglomerates and grey sandy clays with thin lenticular layers of lignite and small lumps of fossil resin. These rocks are very like those of the Wood beds of the Bezuidenhout and Witte Rivers, and some of the fossil plants are common to both areas.

In Knysna there are three basin-like areas of quartzites, sandstones, conglomerates and clay, belonging to the Uitenhage series; the pebbles are mostly of quartzite derived from the neighbouring hills and mountains made of the Table Mountain series. They occupy deep valleys cut out of the Cape formation, and are themselves cut through by the coast-line. Near the village of Knysna these beds are over 600 feet thick; the boulders in the conglomerate are often of large size, in places they average a foot in diameter.

On the right bank of the Knysna estuary at Brenton marine beds occur at sea level; the lowest beds seen are shelly conglomerates containing *Ostrea, Trigonia rogersi,* and fragments of other molluscs; above these come fifteen feet of grey clays with limestone nodules in which there have been found *Nautilus, Belemnites, Acanthodiscus, Trigonia holubi* (?), *Cidaris* spines, stem joints of *Pentacrinus* and *Ptychomya complicata. Perna, Meretrix* and other shells not yet named occur in the clays, but they are in a decomposed state and it is very difficult to remove them from the rock. These beds lie at a lower level than the conglomerates exposed within a few miles to the north, east and west, but on account of the strata being to a great extent hidden by soil and alluvium the relation of the two types of deposit is not yet known.

Along the Bitou River there is a great mass of conglomerates and loose sandy beds with pockets of lignite. The conglomeratic beds in the Bitou basin are peculiar in that the included fragments of rock are angular instead of being well rounded as is usually the case with the pebbles in the Uitenhage conglomerates. The third basin is in the valley of the Pisang River; the beds in it are less conglomeratic and more sandy and clayey than those of the other two areas, and some of the beds are quartzitic owing to the deposition of silica between the grains of the rock. Near Seal Point casts of *Trigonia conocardiiformis* have been found in the sandstones and conglomerates. This is the only marine fossil yet found in the conglomerates of the Enon type, but as it is a very characteristic member of the fauna of the Sunday's River beds its occurrence is of great interest. It is evident that the water in which the Pisang River beds were deposited must have been salt, or at least so near the sea that the shells of the dead bivalves could be washed back into it by strong tides. But the absence of marine fossils from the bulk of the Knysna conglomerates and sandstones can only be interpreted on the supposition that the rocks were laid down in water sufficiently far removed from arms of the sea to be free of marine inhabitants.

The occurrence, which has been already mentioned, of a bed of marine fossils between the red gravels and sandstones north-west of Uitenhage, proves that the sea at one time invaded the non-marine area, and the *Trigonia* of the Pisang River beds points in the same direction. The *Trigonia* of Pisang River proves also that these rocks were formed at about the same time as the Sunday's River beds.

Still farther west, in the divisions of Mossel Bay, Riversdale, Robertson, Swellendam and Worcester there are large areas of conglomerates, sandstones, shales and mudstones, resembling to some extent the Enon beds but containing some varieties of sediments not met with in the Uitenhage Division; and again in the country between the Langebergen and the Zwartebergen, in the divisions of Willowmore, Uniondale and Oudtshoorn, there are large areas of similar rocks that in spite of the absence of fossils must be relegated to the Uitenhage beds.

All these masses of rock occur in a more or less similar manner; they occupy basins partly cut out of the older rocks, but in part due to earth-movements subsequent to the Uitenhage period. They extend far below the present level of the rivers traversing them, and are generally elongated in an east and west direction, roughly parallel to the strike of the older rocks.

The Mossel Bay area is perhaps the most interesting of these patches of Uitenhage beds, for it has yielded several fossils that can be compared with those of the Uitenhage district. It is rather irregular in shape, about fifty miles long from east to west, and at the most fifteen miles wide. The northern boundary is formed by the Langebergen. and the southern in part by the coast between Mossel Bay and Great Brak River, and, west of Mossel Bay, by the Bokkeveld and Table Mountain series. North of Mossel Bay the George granite and the highly altered Malmesbury beds project far into the area of Uitenhage beds, dividing its eastern end into two tongues which join west of the main road to Robinson's Pass. The Uitenhage beds thus rest upon granite, Malmesbury beds, Table Mountain sandstone, Bokkeveld and Witteberg beds at different places; it has been noticed that, to a certain extent, the pebbles and boulders, for the included blocks reach a length of more than eighteen inches in the conglomerates, came from the rocks that are close at hand rather than from those forming the mountains. Thus in the Ruitersbosch Valley there is a large proportion of granite boulders in the conglomerates which are well exposed round the western end of the George granite. Near Bottle's Kop, that curiously shaped hill of quartzite and quartz schist (probably belonging to the Table Mountain series), which is so conspicuous to the north of the Mossel Bay-George road, the conglomerate contains many fragments of the quartzitic rock. Along Weyer's River, and generally along the western border of the conglomerate, pebbles derived from the Bokkeveld beds are very abundant. At Cape St. Blaize the conglomerate is represented only by a very thin layer of breccia, composed of angular fragments of the underlying Table Mountain sandstone. Along the northern boundary Table Mountain sandstone pebbles are by far the most abundant, and this is also the case in the conglomerates lying at a considerable distance above the base of the Uitenhage beds, as at Honig Klip Kloof, where there are magnificent sections through a coarse, white conglomerate, composed almost entirely of pebbles and boulders of Table Mountain sandstone and quartzite; the Honig Klip Kloof conglomerates are interbedded with pale, sandy beds, and probably form about a half of the whole thickness, some 500 feet, exposed along the valley. The pebbles in the conglomerates are usually very well rounded; they must have been rolled about for a long time and reduced to their present form before being buried in the sandy or muddy matrix of the rock.

The beds of conglomerate are by no means confined to the base of the series; they seem to occur at intervals throughout the whole thickness of rock, and are separated by beds of shales, sands or mudstones.

The maximum thickness of the Uitenhage beds in Mossel Bay is rather considerable. They lie comparatively undisturbed, for the angles of dip are low; they certainly descend below sea level in places, and the bed of the Gouritz River, both just below the gorge through the Langebergen and to the north of Roode Hoogte, lies in sandstone and pebble beds of this series; they form practically the whole of the hills between Herbertsdale and the watershed north of the Stink River. The tops of these hills are mostly formed by some twenty feet or less of the surface deposits resting unconformably upon the Uitenhage rocks, but as the average height of the hills is over 1,000 feet the greatest thickness of the Uitenhage beds is probably rather over that amount.

At a spot about three miles east of the village of Herbertsdale there are some shales containing plant remains. Four species have been recognised amongst them, *Cladophlebis denticulata* forma *atherstonei*, which also occurs at Dunbrody in the Wood beds, *Taeniopteris*, also found at Dunbrody, *Osmundites kolbei* and *Taxites*. The shales are very soft and easily weathered, so that the exposures are few. The Herbertsdale outcrop has been opened up for prospecting purposes owing to the presence of small fragments of black lignite, which led to the expectation of a workable deposit of coal. No such reward met the searchers, but their work furnished the means of obtaining the four species of plants mentioned above. In a fairly well-watered country like the Mossel Bay Division soft shales are usually covered up by soil and vegetation, and in the absence of quarries, pits and cuttings, it is extremely difficult to get out any fossils there may be in the rock. Although the Herbertsdale plants are almost the only ones yet found west of the Uitenhage district there must be many more awaiting discovery, and any further specimens will be of very great interest.

Many casts of parts of stems have been found in the hard sandstone of Cape St. Blaize, but hitherto none of them have been determined.

The underlying surface of the Cape formation and Pre-Cape rocks is probably very uneven. In the Lang Touw Valley below Herbertsdale some sections are exposed showing the conglomerates and sands of the Uitenhage beds resting against a steep almost cliff-like face of Bokkeveld beds, the north slope of an old valley running east and west. The west end of the George granite is a high ridge reaching a height of perhaps 1,000 feet above the lowest visible portion of the conglomerates in the Brandwacht Valley to the south, and a less though still considerable height above the conglomerates between it and the Langebergen.

The sandstones of Cape St. Blaize, lying horizontally and unconformably upon the Table Mountain series, which dips steeply southwards, are much harder than the sandy beds of the Uitenhage series usually are, but not far to the west along the coast the beds are much softer, very like the sandy clays that occur north-east of Heidelberg. The Cape St. Blaize rocks form a narrow outlier lying east and west and are separated by about four miles of rough country of Table Mountain sandstone from the large area of Uitenhage beds, which are exposed at sea level near Hartenbosch.

The outlier of Uitenhage beds upon which the village of Heidelberg is built is about thirty miles long from east to west, and eight wide at its broadest part near the west end. It stretches from the west side of the Slang River in Swellendam to Assegaai Bosch in Riversdale, and both the Duivenhoek's and Kaffir Kuil's River traverse it without exposing the underlying rocks. The total thickness of the beds must be considerably over 1,000 feet, for they have a variable and low but on the whole northerly dip throughout. The conglomerates and sands may well have accumulated at moderate angles, and sections along the new railway between Heidelberg and Riversdale show masses of gravel piled up very irregularly and lying between sand and clays which are themselves false bedded. Such sections show that the sediments were deposited in water in which strong and varying currents prevailed. Much of the Heidelberg outlier, however, is composed of thin-bedded shales and mudstones, which must have been laid down in quiet water, although thin pebble beds are frequently found with these fine-grained sediments. The outlier is certainly basin-shaped, and no connection has been traced with the Mossel Bay beds to the east, or with the Swellendam basin to the west. It is probable that subsequent earth-movements have disconnected these basins of Uitenhage beds, aided of course by denudation, which has swept away perhaps the greater parts of the Uitenhage beds deposited in that part of the Colony.

The Heidelberg beds consist chiefly of conglomerates, sands, red and grey mudstones, shales and clays; near Heidelberg there are some peculiar hard white argillaceous beds, which are quarried for foundation-stones, and with them some pale siliceous shales crowded with the thin shells of an entomostracan, *Estheria anomala* (Rupert-Jones), a fossil that is found at many other places in the Heidelberg outlier, but hitherto not known from the Uitenhage district, or from any of the other outliers of the Uitenhage series. At Heidelberg village the clays exposed by the excavations for the railway station contain the *Estheria anomala* and another entomostracan genus, probably *Cypris;* some badly preserved lamellibranch shells closely resembling *Unio uitenhagensis* of the Uitenhage district have been found in the same beds. Some fish scales belonging to a ganoid genus, some indeterminable plant remains, and a wing case of a beetle complete the list of fossils from the Heidelberg outlier. It is certain, however, that a considerable variety of fossils will be found there in the future. The varied nature of the scanty remains mentioned above show that many classes of organisms were represented in the waters in which the Heidelberg beds were deposited, and only careful searching is required to produce good specimens. The most favourable localities for fossil hunting in that district seem to be the Doorn River Valley west of Heidelberg village, the Spiegel River Valley, and the Klein Vette River north-west of Riversdale, but in course of time new exposures will be opened up along roads, and for various other purposes, in places where the rock underlying the soil cannot now be seen.

The beds in which the fossils have been found are grey or whitish in colour; the red clays, sands and marly beds seen to the north of Heidelberg have not proved fossiliferous. It is generally found that red-coloured rocks are not fossiliferous. The red colour is due to the higher state of oxidation of the iron compounds than is the case in the green, blue and grey rocks; when much organic matter was present during the deposition of the mud, the red, highly oxidised, iron compounds were reduced to a less oxidised state, and these give a bluish-green or grey colour to the mud. The amount of organic matter present was of course closely connected with the number of living organisms that might leave traces of their existence in the shape of fossils, hence it is always to be expected that beds that are uniformly red throughout, and therefore to be regarded as having been red when formed, should yield few or no fossils.

On the watershed between the Doorn and Klein Doorn Rivers the cuttings for the new railway line to Riversdale revealed the presence of some limestone bands showing cone-in-cone structure, and a few thin veins of gypsum. The cone-in-cone limestone breaks up in a very curious fashion; the rock appears to be built up of a number of cone-shaped bodies, closely pressed together, with their axes perpendicular to the bedding planes. The gypsum fills narrow cracks and joint planes, and is a product of the mutual decomposition of pyrites and carbonate of lime in the shales.

A very interesting point in the Heidelberg basin is the occurrence of an intrusive plug of melilite-basalt (alnöite) near the northern part of the farm, Spiegel River on the ridge running south from Amandel Bosch Rug (see p. 346).

Near the village of Swellendam there is an isolated basin of Uitenhage beds. Its exact limits are not known, as it and the surrounding rocks belonging to the Bokkeveld-Witteberg series are much hidden by gravels and alluvium of a much later age, but it is about twelve miles long and five wide, and extends from the village, the eastern part of which is built on it, to beyond the Buffeljagt's River. The rock near the western end seems to be chiefly composed of conglomerates containing pebbles derived from the Malmesbury, Table Mountain, Bokkeveld and Witteberg series. At the railway station a bore-hole put down to the depth of 350 feet did not reach the base of the conglomerate. Near the bottom of the hole the bore passed through a boulder of micaceous slate seven feet in diameter. There are but few exposures of these beds, but the railway cuttings east of the village show that there are sandy clays interbedded with the conglomerates.

The Swellendam beds have generally a low, northeasterly dip, and the basin-shaped area occupied by them must in part be due to earth-movements subsequent to their formation.

Two outcrops of red sandstone and conglomerate occur in the bed of the Groot Vader's Bosch Stream and on the hill just south of it, where the main road leaves the valley; these outliers are situated between the Swellendam and Heidelberg basins and point to the former connection of the beds filling them; a careful examination of the district, with particular attention to all excavations and cuttings that may be made, will certainly prove the greater extension of the Uitenhage beds in this area.

In the country south of the Zwartebergen the gravels and other deposits belonging to a comparatively recent period often hide the underlying rocks, and in some cases the gravels may be mistaken for the Uitenhage conglomerates. With the high level gravels there are often associated compact rocks whose grains are cemented together by silica, carbonate of lime, or ferruginous matter, and when once a person is well acquainted with these somewhat peculiar rocks he can readily recognise them in even very small fragments; their presence in a gravel at once distinguishes it from the Uitenhage conglomerates. The high level gravels themselves can usually be distinguished from the Uitenhage beds by the fact that they cover flat hill tops, often bounded on one or more sides by a low step or krantz, due to the gravels offering more resistance to the weather than the underlying rock, whether the latter belong to the Uitenhage beds or the Bokkeveld or Witteberg series. In the Mossel Bay basin excellent sections showing the unconformity of the gravels and surface quartzites to the Uitenhage beds can be seen in the valley of the Nauga River east of Herbertsdale; a fine example of a similar unconformity in the Uniondale Division is shown on Plate XXIII.

West of Swellendam there are two more isolated basins of Uitenhage beds; one stretches from Robertson to Ashton, and the other from south of Goudini Road Station to beyond Nuy, passing just south of Worcester. The beds exposed in these basins are red conglomerates, containing pebbles from all the rock series, from the Malmesbury to the Ecca, which crop out within short distances of the Uitenhage beds. The latter rest unconformably upon the older rocks south of the Worcester fault, and, apparently, to the north of it also in places. The main part of the faulting certainly took place before the Uitenhage beds were formed, but it is not unlikely that here, as in Uniondale and Uitenhage, there was a recurrence of movement along the old line. The area near Worcester, however, has not been examined with a view to settling this point since the post-Uitenhage faulting farther east has been clearly recognised.

The conglomerates are well exposed on the banks of the Kogman's Kloof River above Ashton Station, on the road to Waai Kloof from Worcester, and in a railway cutting just outside Worcester Station.

Between the Langebergen and Zwartebergen a very considerable tract of country in the divisions of Oudtshoorn and Willowmore[1] is occupied by the sandstones and conglomerates of this series. The longest area extends from the west or right bank of the Gamka River below Calitzdorp to near Tover Water Poort, a distance of over seventy miles, but near Meiring's Poort the width of the area is very small, under a mile; south of Coetzee's Poort the width is over twelve miles. Along the northern edge of the area the conglomerates lie directly upon the Cango series; but east of Meiring's Poort they rest upon the Table Mountain sandstone along the northern edge, and upon the Table Mountain and Bokkeveld series on the south. The Olifant's and Gamka Rivers flow for a considerable distance in rocks belonging to this series.

The conglomerates between Coetzee's and Potgieter's Poorts closely resemble those at Enon. They are red rocks, and weather into curiously rugged crags with numerous small caves, and at places two caves on opposite sides of a crag have met, with the result that the crag has a hole through it. These conglomerates were deposited against steep banks formed by the older rocks. The conglomerates as a whole lie at the bottom of the basin, or rather they crop out on its edge, and are probably continuous under the sandstones and shales that occupy a wide area within the basin. Very probably the conglomerates were in part formed near

[1] *G. C.*, iii., p. 76; viii., p. 110.

the sides of the valley while the finer grained sediments were being deposited farther away from the hills. Although the conglomerates are chiefly found in the peripheral portion of the area they are not confined to it, for near Oudtshoorn thick beds of conglomerate occur at a much higher level than the sandstones on which the town is built. The sandstones are seen between Calitzdorp and Vlakte Plaats, and at the town of Oudtshoorn, where they are much used for building purposes. They are rather soft sandstones, not quartzitic, and are usually greenish in colour. The sandstones and shales contain bits of fossil wood, and near Vlakte Plaats masses of lignite sufficiently large to be dug out and used for fuel have been found, but this lignite, as is the case with similar materials elsewhere in the Uitenhage beds, near Herbertsdale and in the Sunday's River Valley, is not found in layers that are thick and constant enough to repay systematic working.

From the Oudtshoorn basin Dinosaurian teeth and fragments of *Cladophlebis* have been obtained.

The depth to which the Uitenhage beds in this basin extend below the surface is not known.

In the Vlakte Plaats area there are two distinct bands of conglomerate, a red band at the base and a white conglomerate higher up in the series; these two bands are repeated in the Georgida basin to the east, which is traversed by the Traka River below Tover Water Poort. Two small patches of Uitenhage beds (of the Enon type) at the head of the Olifant's River[1] are interesting because they lie at a higher level than

[1] *G. C.*, viii., p. 115, and Map attached,

elsewhere in the Colony, probably 3,000 feet above the sea.

In the Baviaan's Kloof there are four long areas of Enon conglomerate and two small ones, and there is another in the Koega Valley.[1] These disconnected patches of Uitenhage beds are of great interest, for the beds often dip at high angles and have been faulted and folded in amongst the rocks of the Cape system.

There is still very much to be learnt about the nature and distribution of the Uitenhage beds in the Colony; the Uitenhage district itself has yielded but a small part of its history, although it has attracted more attention from geologists than any other area in the Colony, excepting perhaps the Cape Peninsula and the Diamond Fields. At present the limits of the marine beds are not known exactly, but they certainly extend to the east as well as to the west of the Uitenhage area.

At the commencement of the Uitenhage period the southern parts of what is now Cape Colony must have been very mountainous. Great valleys with mountains on either side stretched east and west for long distances, and so far had denudation proceeded that all the rock series from the Pre-Cape to the Karroo formation were exposed at the surface. The height of the mountains above the bottom of the valleys was greater than it now is; the amount of rock removed from the mountain ridges since the beginning of the Uitenhage period

[1] *G. C.*, viii., p. 119, etc.; ix., p. 64.

must be very considerable, since it includes a large part of the material now forming the Uitenhage beds as well as that removed since the close of the period. The rivers, which before the deposition of the Uitenhage beds were able to carry away the mud, sand and pebbles delivered to them by the mountain streams, became unable to cope with their work, and their beds consequently became choked up with *débris*, at first as a rule of a coarse nature including many large boulders and pebbles together with a large quantity of sand. These accumulations are the conglomerates that lie below the fine-grained rocks, the Enon beds of the Uitenhage district and the similar rocks of the outliers to the west, but it is by no means certain that the red conglomerates round the Oudtshoorn-Willowmore basin, for example, were formed at precisely the same time as the Enon conglomerate itself. One possible cause of this change of conditions, the change by which the area became one of deposition or accumulation instead of a region in which the destructive agencies had full sway, may have been that the level of the land surface as a whole was reduced with regard to the level of the sea into which the old rivers flowed. Whether such a downward movement of the land took place uniformly or whether some parts were depressed more than others is not easy to determine, although the fact that the marine beds have not been found west of Knysna seems to point to an unequal distribution of the change in level. Had the sinking gone on continuously and equally over the whole area we should expect a gradual extension of similar sediments from the sea landwards, *i.e.*, conglomerates at the bottom, then fine-grained rocks of fluviatile origin, and, finally, marine beds on the top. During the uniform and gradual depression of a tract of country, in the course of which the actual grade or inclination of the river valleys would not be altered, those parts of the valleys left above the level of the sea at any one time would naturally be able to carry on their work as they did before the downward movement set in. In the case of the Uitenhage beds, however, the state of affairs is quite different, no such regular spreading of the deposits from the marine area is noticeable; on the contrary the Uitenhage district is the only one where a series of conglomerates, fluviatile sands and muds and marine beds has been observed, and even there the red conglomerates and sands near the native location at Uitenhage are intercalated with by no means the lowest of the marine beds, showing that a part of the shore of the sea lay round the end of the mountains near Uitenhage some time after the earliest marine beds were formed in the neighbourhood. If the sea ever reached the western outliers of Oudtshoorn, Heidelberg and Swellendam, no trace of its presence has yet been found, and in any case over 1,000 feet of non-marine sediments were piled up before it did so. These filled up the old valleys to the extent of at least 1,000 feet, very probably to a much greater depth, possibly above the level of the lowest passes over the Langebergen and Zwartebergen.

There is, however, another possible cause which would account for the old rivers receiving more *débris* than they could carry away, and that is the coming in of a drier climate than had formerly prevailed.[1] Under such conditions the supply of rock *débris* would be as great as, if not greater than, during the preceding moister period, for the hills would be less protected by vegetation, and the breaking up of the naked rock by change of temperature would proceed rapidly. The occasional rain-storms in such a climate sweep down vast quantities of gravel and sand, rounding off the edges of the rock fragments and thus producing pebbles and boulders of the ordinary shapes. The prevalence of unfossiliferous red-coloured conglomerates and sands, especially near the base of the series, in Uitenhage, Oudtshoorn, Heidelberg, Swellendam, Robertson and Worcester, supports this explanation; and the irregular piling up of much of the red rocks is evidence in the same direction.

The grey shales and muds of the Wood beds in the Uitenhage Division were probably formed in the waters of a river that had direct communication with the sea, for the oyster shells, the *Gastrochæna* in the logs of wood, and the *Pecten*, all found in the Wood beds near Dunbrody, point to the proximity of the sea. The plant-bearing shales near Herbertsdale, and the grey shales with *Estheria* and the other fossils previously mentioned in the Heidelberg area, have not yielded any proof that the water in which they were laid down was in close proximity to the sea. These beds may have been formed in shallow lakes or lake-like expansions of

[1] For an excellent account of the rocks formed under desert conditions, such as here spoken of, the student able to read German should peruse Prof. J. Walther's *Denudation in die Wüste*.

the river which still drained the country. It cannot be held that the valleys were entirely closed, or that they were in a region that had no outlet to the sea; for in such districts the salts that are contained in small quantities in all rocks become concentrated in the water that temporarily or permanently occupies the lowest levels, and form layers of crystalline rock-salt, gypsum and other minerals that are interbedded with the sand and mud carried into the same basins. Incrustations of salt occur on the outcrops of certain sandstones in the valley leading down to the Addo drift,[1] but no beds of rocksalt have been found, though gypsum is disseminated through the Enon beds in some of the Willowmore outliers;[2] but the occurrences are not sufficient to prove that the beds were deposited in closed basins. In the case of the salt-bearing beds the abundance of marine fossils in the strata above and below them shows that the area was not for long, if at all, disconnected from the open ocean; the scattered gypsum crystals in the Enon beds may be compared with the occurrence of that mineral in the soil of certain parts of the west coast area which is freely drained but which receives a low rainfall.[3]

The description of the outliers on previous pages shows distinctly enough that the deposits vary considerably from one basin to another, that although their general nature is very much the same, the order in which they occur is not in the least identical. The position of the outliers also shows that they were formed in separate valleys, in each of which the deposits were

[1] *G. C.*, x., p. 26. [2] *G. C.*, viii., p. 114. [3] *G. C.*, ix., p. 44.

governed by the local conditions. Whether during the later part of the period, represented by beds that have mostly been swept away by denudation, all the outliers were connected, and sediments were spread over the whole of the district in which the outliers occur as well as beyond its limits, must be left to the future to decide. It is quite possible that evidence sufficient to settle the question will be forthcoming.

Whether this was the case or not, the absence of transverse valleys in the Langebergen filled with the Uitenhage beds is specially worthy of note, for it shows that the Oudtshoorn basin was then quite distinct from the valleys south of the Langebergen, and that the rivers which now traverse that range had no existence in those days. The Uitenhage beds both north and south of the Langebergen extend below the present level of the Gamka-Gouritz River bed, and the dislocations undergone by the Uitenhage beds in those areas do not seem to be great enough to account for the complete isolation of the beds on either side of the mountains; the sharply defined gorges of the Gouritz River through the Gamka hills and Langebergen seem to have been cut since Uitenhage times, for they contain no outlier of the rocks that one would expect to find had they been of Pre-Uitenhage age.

Considering generally our present knowledge of the Uitenhage beds, it leads to the conclusion that the depression of the area as a whole, which allowed the sea to encroach upon the previous land surface in the Uitenhage district, was not uniform, but that the grade of some of the valleys was at the same time altered, and that this may have been accompanied by a drier climate.

Regarding the age of the Uitenhage beds, Prof. Seward[1] has, from a study of the plant remains, come to the conclusion that the flora is related to that of both the Jurassic and Wealden (Lower Cretaceous) of other countries, but that the relationship as a whole is closer to the latter than to the former.

The best evidence for the correlation of the Uitenhage formation with foreign beds is furnished by the marine fossils of the Sunday's River beds; the relationship of the different classes of fossils has been carefully discussed by Dr. F. L. Kitchin,[2] and the following account is a summary of his conclusions.

For correlation with the European beds the cephalopods are the most valuable fossils; the South African species of *Holcostephanus* have closely allied forms in the Upper Valanginian and Lower Hauterivian beds, which are the middle part of the Neocomian series; and the genera *Hamites*, *Crioceras*, *Bochianites*, and *Acanthodiscus* are characteristic Cretaceous forms. Some of the *Trigoniae* and several other lamellibranchs are also closely related to European Neocomian species. Certain *Trigoniae*, especially *T. ventricosa* and *T. holubi*, are very closely related to species in the Oomia beds of Cutch, which also contain species of *Seebachia* and *Cucullaea* very like Uitenhage forms. In German East

[1] *A. S. A. M.*, iv., part i., pp. 43-46.

[2] Kitchin, *G. M.*, 1907, pp. 289-95, and p. 480. *A. S. A. M.*, vii., part ii., 1908.

Africa and the north of Madagascar there are Neocomian beds with a few forms identical or closely allied to Uitenhage species; and in South America, in Bolivia, Chili, and the Argentine, there are species of *Trigonia* very like Uitenhage forms.

It is probable that the whole of the Uitenhage formation falls within the Neocomian series, and the fact that no definite subdivisions based on the distribution of the fossils have been found corroborates the conclusion, drawn from the lithological characters of the rock, that the formation was deposited comparatively rapidly.

The following is a complete list[1] of the invertebrate fossils from the Uitenhage series:—

Anthozoa—
- *Isastraea richardsoni* var. *antipodum*, Tate.
- *Thamnastraea*, sp.

Echinodermata—
- *Cidaris pustulifera*, Tate.

Annelida—
- *Serpula* cf. *concava*, J. Sow.
- ,, *pinchiniana*, Tate.

Polyzoa—
- *Berenicea antipodum*, Tate.

[1] These fossils are figured and described in the following papers:—

Krauss, F., "Ueber einige Petrefacten aus der untern Kreide des Kaplandes," *Nova Acta. Acad. Caes. Imp. Leop. Carol. Nat. Cur.*, xxii., part 2, p. 439. Bonn, 1850.

Sharpe, D., *Trans. Geol. Soc. London*, vol. vii., Ser. 2, p. 193, 1856.

Tate, R., *Q. J. G. S.*, xxiii., p. 139, 1867.

Neumayr, M., and Holub, E., "Ueber einige Fossilien aus der Uitenhage Formation im Süd-Afrika," *Denkschr. d. k. Akad. Wiss., Math.-Nat. Classe*, Bd. xliv., p. 267, Wien., 1882.

Kitchin, F. L., *A. S. A. M.*, vii., part 2, 1908.

Lamellibranchiata—

Anthonya lineata, Kitchin.
Astarte (*Eriphyla*) *herzogi* (Goldf.).
,, ,, *pinchiniana*, Tate.
,, *longlandsiana*, Tate.
Cardita nuculoides, Tate.
Corbula? rockiana, Tate.
Cyprina borcherdsi, Tate.
,, *rugulosa*, Sharpe.
Cyrena? baini, Sharpe.
Cucullæa kraussi, Tate.
Exogyra imbricata, Krauss.
,, *jonesiana*, Tate.
Gastrochaena dominicalis, Sharpe.
Gervillia dentata, Krauss.
Goniomya, sp.
Grammatodon atherstoni, Sharpe.
,, *jonesi*, Tate.
Lima (*Mantellum*) *neglecta*, Tate.
,, (*Acesta*) *obliquissima*, Tate.
Lithodomus stowianus, Tate.
Mactra? dubia, Kitchin.
Meretrix uitenhagensis, Kitchin.
Modiola atherstoni, Sharpe.
,, *baini*, Sharpe.
,, *rubidgei*, Tate.
Monodonta hausmanni, Neum.
Mytilus jonesi, Tate.
,, *uitenhagensis*, Kitchin.
Nucula uitenhagensis, Kitchin.
Ostrea, sp.
Pecten rubidgianus, Tate.
,, (*Camptonectes*) *cottaldinus*, d'Orb.
,, ,, *projectus*, Tate.
,, (*Chlamys*) cf. *subacutus*, Lam.
,, (*Syncyclonema*) *orbicularis*, J. Sow.
Perna atherstoni, Sharpe.
Pholadomya dominicalis, Sharpe.
Pinna atherstoni, Sharpe.
,, *sharpei*, Tate.

Lamellibranchiata (*continued*)—
Placunopsis imbricata, Tate.
,, *subjurensis*, Tate.
,, *undulata*, Tate.
Pleuromya baini, Sharpe.
,, *lutraria*, Krauss.
Psammobia atherstoni, Sharpe.
Pteria baini, Sharpe.
Ptychomya complicata, Tate.
Seebachia bronni, Krauss.
Solecurtus, sp.
Tancredia schwarzi, Kitchin.
Thetironia oblonga, Kitchin.
,, *papyracea*, Sharpe.
Thracia, sp.
Trapezium nivenianum, Tate.
,, *? tatei*, Kitchin.
Trigonia conocardiiformis, Krauss.
,, *herzogi*, Goldf.
,, *holubi*, Kitchin.
,, *kraussi*, Kitchin.
,, *rogersi*, Kitchin.
,, *stowi*, Kitchin.
,, *tatei*, Neum.
,, *vau*, Sharpe.
,, *ventricosa*, Krauss.
Unio uitenhagensis, Kitchin.

Gastropoda—
Actæonina atherstoni, Sharpe.
Alaria coronata, Tate.
Limnæa remota, Kitchin.
Monodonta hausmanni, Neum.
Natica atherstoni, Sharpe.
,, *rogersi*, Kitchin.
,, *uitenhagensis*, Kitchin.
,, *? mirifica*, Kitchin.
Neritopsis ? turbinata, Sharpe.
Patella caperata, Tate.
Pleurotomaria, sp.
Turbo atherstoni, Sharpe.

Gastropoda (*continued*)—
Turbo minutulus, Kitchin.
,, *rogersi*, Kitchin.
Turritella rubidgeana, Tate.

Cephalopoda—
Acanthodiscus, sp.
Belemnites sp. 1, Kitchin.
,, *sp.* 2, Kitchin.
,, *africanus*, Tate.
Bochianites glaber, Kitchin.
Crioceras spinosissimum, Neum.
Hamites africanus, Tate.
Holcostephanus atherstoni, Sharpe.
,, cf. *atherstoni*, Sharpe.
,, *baini*, Sharpe.
,, cf. *baini*, Sharpe.
,, *modderensis*, Kitchin.
,, *rogersi*, Kitchin.
,, *uitenhagensis*, Kitchin.
,, *wilmanæ*, Kitchin.
Hoplites subanceps, Tate.
Nautilus, sp.
Phylloceras rogersi, Kitchin.

Crustacea—
Meyeria schwarzi, Kitchin.
Estheria anomala, Jones.[1]

Reptilia—
Algoasaurus baini, Broom.[2]
A Plesiosaur not yet described.

The Cretaceous Rocks of Pondoland.

On the coast of Pondoland the Cretaceous rocks occur in two narrow strips faulted down against the Table Mountain series that forms the greater part of the coastal district.

[1] *G. M.*, 1901, p. 350. [2] *G. M.*, 1904, p. 445.

2. The Umzamba Group.[1]

The larger and more interesting of the two, the Umzamba group, lies near the Natal boundary, stretching from a point about three miles south-west of the Umtamvuna River, which is the limit between the two Colonies, to near the Umtentu River, a distance of some twelve miles. The greatest width of the strip is not more than about 700 yards, for the Table Mountain sandstone crops out in the grass-covered ground at that distance from the shore along part of the coast, elsewhere it approaches the beach more closely and at each end of the Cretaceous outcrops appears on the shore itself. The actual contact of the Umzamba beds with the Table Mountain series has not been observed; it is everywhere hidden by the sand that forms dunes behind the beach and often covers up the Cretaceous rocks. The Umzamba beds lie horizontally, and even where their outcrops are very close to the nearest outcrop of Table Mountain sandstone, as on the right bank of the Umzamba River about 300 yards from the mouth, they are of the same nature as on the shore, and do not show any tendency to become conglomeratic, as would be expected if the junction were an ordinary one of a beach deposit with a shore. The Table Mountain series forms rather high ground close behind the Umzamba beds, rising some 300 feet above them within a short distance.

[1] The name *Umtamvuna beds* has been abandoned because the rocks do not occur on that river. Descriptions of this group and the fossils from it will be found in Bailey, *Q. J. G. S.*, xi., p. 454; Griesbach, *Q. J. G. S.*, xxvii., p. 53; *G. C.*, vi., p. 38; Woods, *A. S. A. M.*, iv., part 7; Chapman, *A. S. A. M.*, iv., part 5.

It is very probable that the junction is a faulted one, like the junction of the Embotyi beds farther to the south-east.

The Umzamba beds form a line of low cliffs (see Plate XXII.) extending about a mile north-eastwards from the sand-spit on the left bank of the Umzamba mouth, and they are also exposed at low tide on the shore between the levels of high and low water, where, however, they are frequently more or less concealed by sand. Between the Umzamba and Umtentu Rivers they are exposed between tide marks only, and do not crop out at the back of the beach below the sand dunes.

The rocks consist chiefly of shelly limestones and hard sandy clays containing much carbonate of lime. These two kinds of rock are interbedded; the shelly limestones are thinner than the clayey beds, and at the same time offer more resistance to the weather and the sea, so that on the low cliffs they appear as projecting shelves or ledges separated by the softer beds. The latter have been deeply worn away by the sea, thus giving rise to lines of caves, whose floors and roofs are the hard shelly limestones. The native name of the cliffs to the north-east of the Umzamba mouth is Izinhluzabalungu ("houses of the white men"), perhaps in reference to the use of the larger caves by a ship-wrecked crew.

The shelly limestones are made up of fragments and perfect specimens of many kinds of shells, mixed with a comparatively small quantity of quartz sand.

Each bed of shelly limestone can be followed for a certain distance along the cliff, then it thins out, and

PLATE XXII.—Cretaceous limestones on the coast about $\frac{3}{4}$ mile N.E. of the Umzamba mouth, Pondoland.

another similar bed at a slightly higher or lower level takes its place.

The sandy calcareous clays are blue in colour on fresh unweathered surfaces, and they are so tough that the fossils contained in them are only with difficulty extracted from the rock, but the outer inch or two of the exposed outcrops are altered to a soft brown clay, from which the fossils are easily obtained by scraping away the decomposed rock with a knife.

The following section measured on the low cliff near the Umzamba mouth illustrates the nature of the succession in these rocks:—

	Ft.	In.
13 Shelly limestone	0	10
12 Tough sandy clay weathering brown . .	1	4
11 Shelly limestone	0	6
10 Tough sandy clay	1	0
9 Shelly limestone	0	4
8 Tough sandy clay	3	6
7 Shelly limestone	0	10
6 Tough sandy clay	3	0
5 Black impure limestone with many shells	0	6
4 Black shale	1	0
3 Oyster-bed	0	2
2 Fine gravelly conglomerate	0	3
1 (At base) Conglomerate with pebbles imbedded in broken shells; many fossils		?
	13	3

The coarse bed at the base of the section is exposed on the shore at low water on both sides of the mouth of the Umzamba, but the extent of the rock laid bare at low tide varies, much of it being at times buried under the sand thrown upon the beach by the waves. A strong spring tide will uncover a wide area of rock that is usually concealed. This bed contains many interesting fossils. Reptiles are represented by Chelonian bones of large size; the characteristic bony plates of the shell or shield and the shoulder girdle are easily recognised; another reptile is represented by large jawbones with pointed teeth. Sharks' teeth are rather abundant, and complete the list of vertebrate fossils. The remains of marine invertebrates are plentifully preserved in this bed, the Cephalopods are represented by at least five species of Ammonites, a *Nautilus* and a *Baculites;* Gasteropods by *Rostellites*, *Eriptycha*, *Pseudomelania*, and a large thick-shelled species of *Pyropsis;* Lamellibranchs by three species of *Pecten*, *Pectunculus africanus*, *Protocardia hillana*, *Trigonia elegans*, *Nemodon natalensis*, *Cardium denticulatum* and *Inoceramus*. In this lowest bed there are many logs of wood, blackened and partly silicified and often bored into by *Teredo*, whose shells are still at the end of the holes made by their former inhabitants. Many of these fossils are much waterworn, and their surfaces are in consequence abraded. The more delicate shells are rarely or never found in a perfect condition, and a considerable part of the rock is made up of fragments of various kinds of shells. These facts, together with the presence of pebbles of grits, sandstone and dark-coloured slates, undoubtedly point to the bed having been formed in shallow water, at the bottom of which the pebbles and shells were rolled about until they were covered up by the overlying deposit. The absence of the thin-shelled easily-broken fossils, such as *Hemiaster* and *Cassidulus*, two echinoderms that are abundant in the overlying fine-grained beds, leads to the same conclusion.

The shelly limestones also contain the stronger shells in a perfect state; some of the weak shells, such as *Inoceramus*, that break up into small fragments of peculiar shape, can be recognised in these beds, but they are only found complete or nearly so in the fine-grained beds. The shelly limestones seem to have been formed in shallow water, for most of the shells were rolled about, broken, and had the projecting points rubbed off their outer surfaces before they came to rest and were buried under the accumulating sediments.

The fine-grained sandy calcareous clays contain strong and delicate shells in an excellent state of preservation. These beds were laid down in quieter water than the shelly limestones, and in consequence the most delicate shells were buried under the sand and mud without being broken. Over thirty species of Foraminifera and Ostracods have been found by Mr. Chapman in some small lumps of the rock that were sent to him for examination.

The lowest bed in the section given on a previous page is the most persistent of the whole series. The rest of the rocks are separated into many beds by the thin lenticular shelly limestones in such a way that two sections measured about a hundred yards apart would not show precisely the same arrangement of beds. This group of rocks was formed near the shore of a sea teeming with life; the shelly limestones were deposited where strong currents prevailed, for a certain period, over a comparatively small area, which were replaced

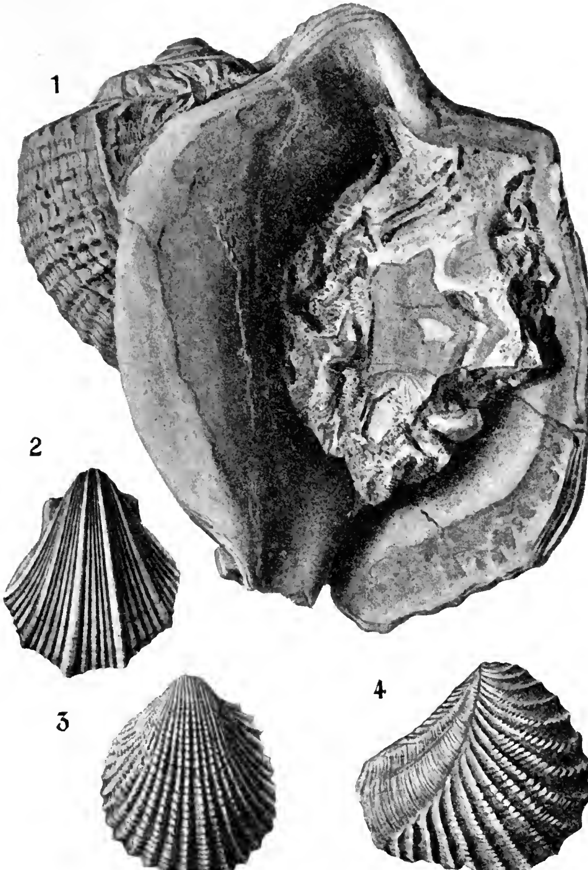


Fig. 27.—Fossils from the Umzamba beds.

1. *Pyropsis africana*, Woods.
2. *Pecten (Neithea) quinquecostatus*, Sow.
3. *Cardium denticulatum*, Baily.
4. *Trigonia elegans*, Baily (after Woods).

by quiet water that allowed the fine-grained sandy mud to accumulate. The whole thickness of rock at present exposed is but some thirty feet, and it exhibits

FIG. 28.—Ammonite, *Mortoniceras soutoni* (Baily) (reduced) after Woods, from the Umzamba beds.

this alternation of fine and coarse sediments throughout. The same species of mollusca appear to be distributed through the whole group, but their presence in any one layer depends upon whether they were strong enough to resist the destructive action of the sea during the formation of that bed, for the coarse sediments contain the strong-shelled species only in recognisable condition, while the fine-grained beds contain both the thick and thin shelled species.

The following is a complete list of the invertebrate fossils from the Umzamba beds :—[1]

Foraminifera—

Haplophragmium neocomianum, Chapman.
,, *meridionale*, Chapman.
Bulimina trigonula var. *inornata*, Chapman.
Pleurostomella subnodosa, Reuss.
Nodosaria prismatica, Reuss.
,, *zippei*, Reuss.
Vaginulina humilis, Reuss.
,, *legumen*, Linn.
,, *intumescens*, Reuss.
Cristellaria subalata, Reuss.
Polymorphina ? gibba, d'Orbigny.
Globigerina canaliculata, Reuss.
Truncatulina schloenbachi, Reuss.
Pulvinulina elegans, d'Orbigny.
,, *carpenteri*, Reuss.
,, *reticulata*, Reuss.
,, *pondensis*, Chapman.
Rotalia soldanii var. *nitida*, Reuss.

[1] Descriptions and further information will be found in Baily, W. H., *Q. J. G. S.*, xi., 1855, p. 454.

Griesbach, C. L., *Q. J. G. S.*, xxvii., 1871, p. 53.

Chapman, F., *A. S. A. M.*, iv., pt. 5, 1904, p. 221. (Foraminifera and Ostracoda.)

Woods, H., *A. S. A. M.*, iv., pt. 7, 1906, p. 275. (Contains also a description of the Polyzoa by W. D. Lang.)

Echinoidea—

Cidaris, sp. cf. *hirudo*, Sorig.
Pseudodiadema griesbachi, Woods.
Cassidulus umbonatus, Woods.
Cardiaster africanus, Woods.
Hemiaster forbesi, Baily.

Polyzoa—

Berenicea gracilis, M. Edw.
Elea meridiana, Lang.
Membranipora irregularis, d'Orb.
,, *perforata*, Reuss.
Eschara royana, d'Orb.
,, *delarueana*, d'Orb.

Lamellibranchiata—

Nuculana, sp.
Arca, sp.
Barbatia meridiana, Woods.
,, sp.
Trigonoarca capensis, Griesb.
Nemodon natalensis, Baily.
Pectunculus africanus, Griesb.
Trigonia shepstonei, Griesb.
,, *elegans*, Baily.
Mytilus.
Modiola kaffraria, Woods.
Pecten (*Chlamys*) *amapondensis*, Griesb.
,, ,, *capensis*, Woods.
,, (*Æquipecten*) *kossmati*, Woods.
,, (*Camptonectes*), sp.
,, (*Neithea*) *quinquecostatus*, Sow.
Ostrea, sp.
Exogyra, sp.
Inoceramus expansus, Baily.
Astarte griesbachi, Woods.
,, (*Eriphyla*) *lenticularis*, Goldf.
Crassatellites africanus, Woods.
Meretrix umzambiensis, Woods.
,, *euglypha*, Woods.
Protocardia hillana, Sow. *var.*

Lamellibranchiata (*continued*)—
Solecurtus? Azor? sp.
Teredo, sp.
Liopistha (*Psilomya*) *corrugata*, Woods.
Goniomya, sp.

Scaphopoda—
Dentalium, sp.

Gastropoda—
Margarita radiatula, Forbes.
Nerita umzambiensis, Woods.
,, *kaffraria*, Woods.
Pseudomelania sutherlandi, Baily.
,, *oonia*, sp.
Scala ornata, Baily.
Solarium bailyi, Gabh.
Natica (*Lunatia*) *multistriata*, Baily.
Gyrodes, sp.
Turritella (*Zaria*) *bonei*, Baily.
Aporrhais, sp.
Dicroloma (*Perissoptera*) sp.
Pugnellus auriculatus, Woods.
,, sp.
Cryptorhytis rigida, Baily.
,, sp.
Pyropsis africana, Woods.
Pirifusus bailyi, Woods.
Semifusus? (*Mayeria?*) sp.
Volutilithes, sp.
Turris? kaffraria, Griesb.
Cancellaria meridionalis, Woods.
,, sp.
Rostellites capensis, Woods.
Actæon, sp.
Actæonella (*Trochactæon*), sp.
Eriptycha perampla, Woods.

Cephalopoda—
Nautilus, sp.
Phylloceras, 2 sps.
Hauericeras gardeni, Baily.

Cephalopoda (*continued*)—
- *Hauericeras rembda*, Forbes.
- *Pseudophyllites indra*, Forbes.
- *Tetragonites*, sp. [*aff. cala*, Forbes].
- *Gaudryceras kayei*, Forbes.
- *Holcodiscus*, sp.
- *Schloenbachia umbulazi*, Baily.
- *Eulophoceras natalense*, Hyatt.
- *Mortoniceras soutoni*, Baily.
- ,, *stangeri*, Baily.
- *Heteroceras*, 2 sps.
- *Hamites* (*Anisoceras*) *subcompressus*, Forbes.
- ,, ,, *indicus*, Forbes.
- ,, ,, sp.
- *Baculites sulcatus*, Baily.
- ,, *bailyi*, Woods.
- ,, *capensis*, Woods.
- *Scaphites*, sp.

Ostracoda—
- *Macrocypris simplex*, Chapman.
- *Bythocypris simulata*, Jones.
- *Cythere? drupacea.*
- *Cythereis ornatissima*, Reuss, var. *reticulata*, Jones and Hinde.
- *Cytheridea longicaudata*, Chapman.
- *Cytheropteron elongato-concentricum*, Chapman.
- *Cytherella williamsoniana*, Jones.

Vertebrata—
- Teeth of sharks.
- Jaw bones of a reptile related to *Mosasaurus.*
- Chelonian bones.

We owe the most complete discussion of the relationship of the Umzamba fossils to Mr. Henry Woods, who came to the conclusion that the fauna belonged to the Campanian or the lower part of the Upper Senonian; the most important fossils leading to this conclusion are *Pseudophyllites indra, Gaudryceras kayei, Hauericeras rembda* and *Hamites indicus.* The fauna is related to that of the Aryalur, Valudayur and *Trigonarca* beds of the east coast of the Indian Peninsula, and also to that of European Senonian strata, but in the latter case there are fewer species identifiable with Pondoland forms. The Umzamba beds have representatives in Zululand (Umkwelane Hill), at Sofala, and in Madagascar.

3. The Embotyi Group.

Near the mouth of the Embotyi River, about seventeen miles north-east of St. John's, there is a group of conglomerates and green sandstones stretching about four miles south-west from Waterfall Bluff. At the south-western end of the outcrops the beds lie nearly horizontally, and behind them are shales and sandstones probably belonging to the Ecca series, which have a rather high dip to the south-east. The junction of the two groups has not been seen, but it is very probably an unconformity. Farther to the north-east the Embotyi beds dip at moderate angles to the north-east, north and south, showing that they have been considerably disturbed since their deposition. At the north-eastern end of the exposures the Embotyi beds rest against a cliff of Table Mountain sandstone, and the slickensides still visible on part of the cliff, together with other evidence in the conglomerate itself, prove that the Embotyi beds have been faulted down against the older rock. The line of fault runs westwards from Waterfall Bluff, and about two miles from the latter separates the Table Mountain sandstone from the Ecca beds. Waterfall Bluff is a vertical cliff, some 300 feet high, whose base is washed by the sea; the streams from the country behind the cliff fall over it, hence its name. The westward prolongation of the line of cliffs coincides with the foot of the escarpment on which the Egossa Forest stands.

The finer grained portions of the beds, which appear on the shore near the mouth of the Umgwegwane River, are green shales and sandstones containing fragments of blackened wood, the only organic remains hitherto found in the group. Further search in these rocks is likely to be rewarded by the discovery of plant remains that cannot fail to be of great interest, and it is to be hoped that the search will be made before long.

The conglomerates towards the south-west end of the outcrops are pebbly rocks with water-worn fragments of dark grits and mudstones, certainly derived from the underlying Karroo beds. North-east of the Umgwegwane River the conglomerate becomes extremely coarse, and bedding planes are often difficult to find. Near the conical green hill on the Waterfall Bluff side of the river, and between that hill and the Bluff, immense blocks of coarse and fine-grained dolerites are found interbedded in a matrix of smaller boulders of similar material and of dark grits, mudstones and shales like those in the conglomerate farther south-west. Some of the dolerite blocks measure twenty feet in length. This conglomerate is the most tumultuous-looking rock in the Colony; magnificent exposures of it can be seen on the seaward face of the green hill, and near Waterfall Bluff. The irregular spaces between the boulders are sometimes filled with radiating bunches of brown calcite. The fine-grained portion of the rock is greenish and very similar to the sandstones near the Umgwegwane mouth.

The occurrence of the dolerite boulders in the Embotyi rock is of great interest, as it proves that the dolerites had been injected into the Karroo formation before the deposition of the conglomerates, and were exposed at the surface during their accumulation. The similarity in situation of the Embotyi group to that of the Umzamba beds, which crop out at a distance of some twenty-four miles to the north-east, and the fact that they are both faulted down against the Table Mountain sandstone, thus belonging to an earlier age than the chief disturbances that have affected this part of the Colony since the close of the Karroo period, make it probable that the Embotyi group belong to the same series as the Umzamba beds. They may be regarded as the basal portion of the Pondoland Cretaceous rocks, and as bearing the same relation to the marine Umzamba beds as the Enon type of the Uitenhage series does to the Sunday's River beds.

4. The Need's Camp Series.

A few years ago Mr. J. W. Woods of East London sent to the South African Museum a collection of rocks containing fossils from Need's Camp on the Buffalo River twenty miles from the sea and some 1,100 feet above sea level. The rocks are shelly and polyzoan limestones, and from Mr. Wood's description it is clear that they rest unconformably upon dolerite intrusive in the Beaufort beds.

The fossils from these rocks have been described by Mr. Henry Woods and Mr. Lang,[1] who found that they have Upper Cretaceous affinities, but that there was not sufficient evidence to decide whether the beds are of Senonian or Danian age.

Prof. Schwarz[2] has recently described similar beds from the Albany and Alexandria Divisions under the name of the Alexandria formation, but he also includes in it the marine pebbly limestones which rest unconformably upon the Sunday's River beds in the Uitenhage Division and which are probably much later in age than the Upper Cretaceous. Some of the shelly limestone from Need's Camp has a remarkable resemblance to the hard foraminiferal glauconitic limestone found some 1,200 feet above sea level near Sand Flats.

FOSSILS FROM THE NEED'S CAMP SERIES.[3]

	Distribution in Foreign Beds.
Anthozoa—	
Caryophyllia, sp.	Cretaceous to recent.
Echinoidea—	
Coptosoma capense, Woods	Genus from Cretaceous to recent.
Cidaris	Rhætic to recent.
Brachiopoda—	
Thecidea (*Lacazella*) sp.	Jurassic to recent.

[1] *A. S. A. M.*, vii., part 1. A more recent discussion of the subject by R. B. Newton will be published in the *Trans. Roy. Soc. S. A.*, vol. i.

[2] *T. G. S. S. A.*, vol. xi.

[3] "Polyzoa and Anthozoa from the Upper Cretaceous Limestones of Need's Camp, Buffalo River," W. D. Lang, *A. S. A. M.*, vii., pt. i., 1908, and "Echinoidea, Brachiopoda, and Lamellibranchia from the ——" Henry Woods, *ibid.*

	Distribution in Foreign Beds.
Lamellibranchia—	
Ostrea, sp.	
Ostrea (*Exogyra*) sp.	Jurassic and Cretaceous.
Pecten (*Neithea*) sp.	Cretaceous to recent.
Perna, sp.	Triassic to recent.
Polyzoa—	
Diastoporidæ—	
Filisparsa ramosa, d'Orbigny	Turonian and Senonian.
,, *fragilis*, Marsson	Senonian.
Diastopora compressa, Goldfuss	Senonian.
Idmoneidæ—	
Idmonea virgula, d'Orbigny	Neocomian and Cenomanian.
Crisina cenomana, d'Orbigny	Cenomanian.
,, *excavata*, d'Orbigny	Senonian.
,, *marginata*, d'Orbigny	Turonian and Senonian.
Tervia dorsata, von Hagenow	Senonian.
,, *gibbera*, Gregory	Senonian.
,, *decurrens*, Pocta	Cenomanian.
Entalophoridæ—	
Entalophora virgula, von Hagenow	Neocomian to Danian.
,, *conjugata*, von Reuss	Cenomanian.
,, *echinata*, Römer	Cenomanian to Danian.
,, *madreporacea*, Goldfuss	Cenomanian to Danian.
Spiropora verticillata, Goldfuss	Neocomian to Danian.

CHAPTER XI.

VOLCANIC PIPES YOUNGER THAN THE STORMBERG VOLCANOES.

In many parts of the Colony there are remarkable pipes, channels through which materials were thrown from the lower region of the earth's crust to the exterior, and now filled with substances of different kinds, sometimes clearly of volcanic nature, but often of such peculiar character that their volcanic origin is not obvious and can only be surmised from the manner in which the rocks occur.

The first of these pipes to be discovered was the Jager's Fontein Mine, in 1870, but those at Du Toit's Pan, Bult Fontein, Colesberg Kopje (Kimberley Mine), and De Beers were found soon afterwards.[1] These discoveries were entirely due to the finding of diamonds, which had been met with by chance near the Orange River three years previously. It was, of course, some time after the diamond mines were opened that their nature was understood.[2] The earliest search for

[1] For an interesting and fully illustrated account of the early discoveries and of the whole history of the diamond mines and their working, see *The Diamond Mines of South Africa*, by Mr. Gardner F. Williams, 1905.

[2] Cohen, *Neues Jahrb. f. Min.*, p. 857, 1872. This paper, or letter, contains the first suggestion of the volcanic nature of the pipes.

diamonds was carried on in the alluvial deposits or "River diggings" on the Orange and Vaal Rivers; the later or "Dry diggings" in the volcanic pipes, which have been the source of so great an industry in South Africa, followed upon the discoveries mentioned above.

Since then scores of these pipes and many fissures have been discovered, and their number is continually being added to. Their wide distribution throughout South Africa is proved by their discovery in East Griqualand, the Central Transvaal, Southern Rhodesia, Gordonia, German South-West Africa, Van Rhyn's Dorp and Riversdale. They appear, however, to be most numerous in the Orange River Colony and the adjoining portion of Cape Colony.

The neck on the farm Spiegel River in Riversdale is of very great interest, as it affords more evidence of the later origin of this class of vents than is obtainable farther north, and it is at one end of the group in a petrological sense, as it is filled with the well-known but scarce igneous rock melilite-basalt (alnöite).

The Saltpetre Kop (Sutherland) vents stand at the other end of the petrological series in being almost entirely filled with fragments of sedimentary rocks.

There are many intermediate conditions between the two extreme types and nearly every gradation has so far been recognised.

We shall commence the description of the pipes with an account of those filled with rocks of the purely igneous type, and proceed in the order of their departure from this type without regard to their geographical positions. At the end of the description the reasons for considering the whole group as belonging to one period of volcanic activity will be given, together with other points of general interest.

On the farm Spiegel River in the Riversdale Division there is a most remarkable mass of melilite-basalt (alnöite) exposed at the top of a hill composed of conglomerates and sandy beds belonging to the Uitenhage series.

The area occupied by the alnöite, as shown by artificial cuttings, is somewhat pear-shaped and measures 300 yards in a north-east and south-west direction and 220 yards across the widest part near the south-west end, but the outcrops are only seen over a small area. The junction with the surrounding beds has not been exposed.

The grey-black igneous rock is in places roughly columnar, but the columns are very feebly developed; they slant towards the east. The only feasible explanation of the occurrence is that the melilite-basalt fills a volcanic neck. The want of good exposures and the crumbly nature of the conglomerates prevent the observation of the dip of these beds at the contact. The beds are seen at several places within 200 to 300 yards of the vent, but they present no points of difference from their nature at a greater distance from the spot. No other neck or intrusion has yet been found in the Uitenhage beds, and till lately no other occurrence of melilite-basalt had been observed in South Africa. The rock is composed of a ground mass of glass in which there are minute crystals of perofskite and magnetite, irregular grains of augite, immense numbers of melilite crystals showing the usual characters of that mineral, and fairly large well-formed crystals of olivine. It is in a remarkably fresh state for so basic a rock.[1]

The vents and semicircular dyke on the Commonage near Sutherland village are mostly filled with rocks of a thoroughly igneous character; tuffs, or rocks made up of small fragments of various kinds, including lava and minerals derived from it, are found in three or four of the seven necks, but with them are the igneous rocks; in the case of three of the pipes the igneous rock is melilite-basalt with more glass and biotite and less augite and melilite than the Spiegel River rock contains; serpentine, calcite and zeolites, the products of alteration of the other constituents, are abundant.[2] The curved dyke is composed of a similar rock. The tuffs in the vents in which the melilite-basalt occurs are light blue sandy rocks containing biotite, ilmenite, serpentine and perofskite in addition to the *débris* derived from sedimentary beds. The other vents on the Commonage are filled with a dark-coloured amygdaloïdal basic glass, and in some cases blocks of sandstone and shale with smaller fragments of the same rocks are imbedded in a matrix evidently composed mainly of altered glass of the nature of the glassy lava in these vents. Serpentine pseudomorphs after olivine are the only large crystalline constituents of this lava, and they appear to have come from another rock, a fine-grained highly altered material

[1] An analysis by Mr. Lewis, one of the Cape Government analysts, is given in *G. C.*, viii., p. 51. A figure of a thin section of the rock will be found in Harker's *Petrology*, fourth edition, p. 160.

[2] Descriptions of these rocks will be found in *G. C.*, viii.

which still adheres to the serpentine pseudomorphs; augite and magnetite are the other constituents that have been recognised, and they are in very minute grains and crystals. The steam-holes in this lava are filled with calcite, analcite, natrolite, and other zeolites, but silica, which in the form of quartz or chalcedony is frequently found in the steam-holes of the ancient Zeekoe Baard lavas and those of the Stormberg series, has not been found in the Sutherland Commonage amygdaloids.

At Matjes Fontein, a farm nine miles south-east of Sutherland, there is a pipe partially filled with melilite-basalt of rather peculiar characters[1] and partly with a gritty breccia containing large fragments of granite, dolerite of the Karroo type, quartzite and other sedimentary rocks, mica, ilmenite and hornblende. The three latter constituents are identical in nature with the same minerals in the Silver Dam pipe to be mentioned presently. The melilite-basalt of this outcrop is composed of olivine, melilite, perofskite, biotite, magnetite, calcite and serpentinous fibres, probably derived from a glassy ground mass. Excepting the presence of calcite and the serpentine fibres the rock is remarkably fresh, and differs in several respects from the other melilite-basalts. It shows a marked flow-structure.

In the remaining pipes there is no large body of igneous rock corresponding to the melilite-basalts and the glassy lava described above.

At Silver Dam, a part of the farm Matjes Fontein in Sutherland, there is a breccia-filled pipe about 180 feet

[1] See *G. C.*, viii., and *T. P. S. S. A.*, vol. xv., 1904, p. 61.

in diameter marked on the surface by a shallow pan. No outcrops of the breccia are visible, but two prospecting shafts allow one to obtain good specimens of the rocks. The breccia is softer in one part of the pipe than elsewhere, and consists of a serpentinous matrix containing fragments and boulders of quartzite, sandstone, shale, dolerite of the Karroo type, and peculiar rocks with a granulitic structure; the last-mentioned rocks are composed of three varieties of monoclinic pyroxene, brown hornblende, brown mica, ilmenite, garnet and some felspar or the alteration products of a basic felspar. The felspar is only present in some varieties of the granulites, which are evidently related, in the sense of forming a series of increasing basicity. It is worthy of remark that olivine and rhombic pyroxenes are absent from these rocks, though the former, altered to serpentine, is an abundant constituent in the matrix of the breccia.

Similar granulitic rocks of variable composition have been found to be abundantly represented in the blue-ground of many of the pipes in Northern Cape Colony. The minerals which occur in these heavy basic rocks are also the most conspicuous fragments in the breccia, and there is no doubt that they were derived from the same source that the boulders came from. The less conspicuous constituents of the breccia, only determinable under the microscope, are perofskite, serpentine pseudomorphs after olivine, grains of quartz and argillaceous matter derived from sedimentary rocks and calcite. The harder variety of breccia contains less serpentine and more sand and clay than the softer, but all the minerals mentioned above occur in both kinds.

Saltpetre Kop is a very prominent hill in the Sutherland Division, rising about 1,000 feet above the general level of the high plateau on which it stands. It is composed of breccia and tuff, filling a vent about 1,000 yards long by 600 wide. The vent traverses the Beaufort beds which are turned upwards for a considerable distance on all sides; the dip of the Beaufort beds is extremely slight in the surrounding district, but at points about a mile and a quarter from the neck the strata have a distinct dip away from it and the inclination increases as the neck is approached, so that near the breccia the beds are nearly vertical.[1] Round about this large neck are nineteen others of smaller size and forty-six dykes, mostly filled with fine tuffs or breccias. In the case of one dyke the rock has been found to be largely composed of one of the less basic plagioclase felspars, and is evidently an igneous rock of somewhat peculiar character, but it has been greatly altered by the substitution of calcite, hydrated ferric oxides, and silica for some of its original components. The breccias and tuffs vary greatly, but they all consist mainly of fragments of sedimentary rocks set in a matrix of similar substances finely comminuted; but in addition to these constituents there are pieces of granite, gneiss, mica schist and Karroo dolerite, and also mica, hornblende and ilmenite, identical in character with the similar minerals in the Silver Dam breccia. Parts of the breccias and tuffs are strongly impregnated with carbonates of lime and magnesia, barium sulphate, hydrated oxides of iron and

[1] A fuller description and plans of the Saltpetre Kop area will be found in *G. C.*, viii., and *T. P. S. S. A.*, vol. xv., p. 61.

silica. This has happened chiefly in the smaller pipes and in the peripheral portion of the large vent; a similar process has caused the hardening of the shales and sandstones at their contact with the vents and dykes. The carbonates, sulphates, oxides of iron and silica were probably carried to their present position by water ascending the channels of eruption after the period of violent activity had closed; their deposition may be regarded as analogous to the effects of the "solfataric" stage of recent volcanic areas.

The smaller necks in the Saltpetre Kop area do not materially affect the regularity of the quâ-quâ-versal dip about the central vent.

In no other vent of the kind we are dealing with in this chapter is the outward dip or up-turning of the surrounding strata so strongly marked as in the case of the central neck of the Saltpetre Kop group. Wherever the strata in immediate contact with one of the pipes are exposed, and have been examined with attention, they have been found to dip away from the contact, as though the ascent of the materials filling the pipes had bent the edges of the strata upwards. This has been noted at some of the Sutherland Commonage vents, at Balmoral (Ratel Fontein), at Matjes Fontein, Schiet Fontein and at Kimberley. This feature seems to be peculiar to these vents, for where notice has been taken of the dip of the strata near the pipes of volcanoes of the more usual types, the strata have been found to be inclined towards the pipe as though dragged downwards by the settling of the contents after the activity of the volcanoes ceased.

On the farms De Vrede, Portugal's River, and Blaauw Blommetjes Keep, in the Sutherland Division, there are breccia-filled pipes and dykes. The Blaauw Blommetjes Keep pipe gives off a sheet-like extension of the breccia, which distinctly traverses a thick sheet of dolerite, and thereby proves that the production of the vent was posterior to the consolidation of the dolerite, a strong confirmation of the evidence afforded by the fragments of coarsely crystalline dolerite found in the breccias of many of the necks of this class.

Three small necks of a similar type occur together on the boundary between Kafir's Kolk and Grenaat Kop in Prieska. The breccia which fills them is almost entirely composed of indurated fragments of the Dwyka series, the formation through which the pipes pass, but there are also fragments of an igneous rock allied to "blue-ground". Grenaat Kop itself and the ridges farther south of it are composed of Dwyka shales which have been considerably silicified, evidently as the result of heated water ascending along certain lines of fracture and brecciation in the strata, just as in the case of Saltpetre Kop. This system of fissuring extends in a north-north-westerly direction along the belt of altered sediments, and it is noteworthy that not only are the above-mentioned pipes situated along this line but there are as well at least three dykes composed of blue-ground and possessing a similar direction.

A large agglomerate-filled pipe penetrates the Malmesbury beds of the Kobe Valley in Van Rhyn's Dorp;[1] it resembles in some respects the necks of the Saltpetre

[1] *G. C.*, ix., p. 41.

Kop group. Through a dark red matrix angular or sub-angular fragments of granite, quartzite, crystalline limestone, and other rocks up to eight feet in length are distributed promiscuously.

At Balmoral (Ratel Fontein)[1] in the Fraserburg Division there is a circular depression in the ground about 300 feet across and from ten to twenty feet deep, surrounded by the truncated edges of the Beaufort beds, which dip away from the breccia filling the pipe. The breccia is a soft muddy blue rock containing fragments of sandstone and shale, dolerite, and pieces of biotite, garnet and ilmenite. The pipe is remarkably well exposed, and the nature of the contact and the upturning of the edges of the strata through which the pipe passes can be very clearly seen.

We now come to the consideration of that class of pipe which is filled with the peculiar material known as "blue-ground," the type that is so well represented in the districts of Carnarvon, Victoria West, Britstown, Philipstown, Hanover, and especially in Kimberley and Barkly West. A full account of the Kimberley group has been given by Gardner Williams,[2] while short notes on some of the little known pipes of Northern Cape Colony will be found elsewhere;[3] only brief references therefore will be made to a few of these.

The Kimberley Mine is the richest and deepest of the De Beers group. The pipe is rudely elliptical in sec-

[1] *G. C.*, v., p. 60.

[2] G. F. Williams, *The Diamond Mines of South Africa*, etc., New York, 1905.

[3] *G. C.*, xi., p. 135; xiii.

tion; the main shaft has been carried down to a depth of about 2,700 feet, but one of the "prospect shafts" has been continued 300 feet deeper.

The De Beers Mine is larger than the Kimberley and second to it in richness, but a portion of the "blue-ground" is not rich enough to repay extraction. The workings have reached a depth of 2,400 feet.

In the early days of this mine there was a dyke of a hard variety of kimberlite traversing the ground in the pipe in a crooked fashion and consequently known as "The Snake," whence the term "snake rock". Each of these pipes has been proved through the rocks of the Ventersdorp system into the underlying granite.

The Bultfontein Mine is noteworthy on account of the huge masses of brecciated dolerite in the pipe. Beautiful crystals of various zeolites, especially apophyllite, are found in it, usually in the spaces between the blocks of dolerite.

The Dutoitspan and Wesselton Mines both give a low yield of diamonds. The former mine is the largest of the group.

The yield of diamonds per 100 loads was in 1908 as follows: Kimberley, 37 carats; De Beers, 37; Bultfontein, 32; Dutoitspan, 23; and Wesselton, 27.

Though the various outside mines, of which hardly a single one is now (1909) being worked, show many points of geological interest, it is only possible to refer to those of the Newlands[1] group which are situated in the Harts River Valley. There are four small pipes

[1] R. Beck, *Zeitsch. für prakt. Geol.*, 1898, p. 163. W. Graichen, *ibid.*, 1899, p. 417.

which are connected underground by a narrow dyke of hard blue-ground. Some of the boulders of eclogite from these mines were found to contain small diamonds.[1] This matter will be referred to again later.

In outline some of the pipes are more or less oval, but frequently they are much elongated or irregular in shape, or may even form long dyke-like masses cutting through the country rock. They can generally be designated *Pipes* or *Fissures* according to their form.

The section of every pipe shows variation of contour, sometimes considerable, at different depths; the walls of most pipes exhibit in consequence frequent hollows and protuberances. A bodily deflection of the pipe is not uncommon, *e.g.*, the Kimberley and Newlands Mines, while in the St. Augustine's Mine, at Kimberley, the pipe has a twisted course. The Smith-Weltevreden Mine in the Harts River Valley has apparently been formed by the coalescence of two pipes, for it is dumb-bell shaped in plan.

The relation between pipes and fissures is a very intimate one, and the majority of pipes have dyke-like offshoots either at the surface or deeper down. It is not uncommon to find that a pipe is of slightly later age than the fissure on which it is situated; less frequently dykes are found cutting across the material filling a pipe. In either case the two kinds of rocks show lithological differences. It has also been found by experience that the material in dykes and fissures rarely contains diamonds.

[1] T. G. Bonney, *G. M.*, 1899, p. 309.

To the peculiar material filling the pipes and fissures, commonly called "Blue-ground," Carvill Lewis[1] gave the name *Kimberlite;* he distinguished three varieties, kimberlite proper, a porphyritic ultrabasic lava, kimberlite breccia, and kimberlite tuff, but these varieties pass into one another by insensible gradations. In this book the term kimberlite will be used to cover all these kinds of rock, as indeed has been the general practice of late years. It is difficult to describe the exact nature of kimberlite, because the rocks, especially their ground mass, have always been altered even in specimens obtained from the deepest parts of the mines.

While rocks are occasionally obtained that show unmistakable structures characteristic of lavas, such as amygdales arranged in bands, the fragmental nature of most of the material called kimberlite is equally clear. It will be shown later that there is reason to believe that Carvill Lewis' kimberlite proper is very closely allied to, if not identical with, melilite-basalt.

The rock as obtained from deep workings has a dark slaty-blue or bluish-green colour, and from that character it got the name "Blue-ground"; near the surface, where it has been more weathered, it has a yellowish-brown tint, and in this condition is termed "Yellow-ground". The depth at which the yellow gives place to the blue ground varies greatly according to the nature of the rock and other circumstances.

Kimberlite is generally a serpentinous breccia containing fragments of various minerals, the chief of which

[1] Carvill Lewis, *Papers and Notes on the Genesis and Matrix of the Diamond*, London, 1897.

are olivine, diopside, chrome-diopside, enstatite, brown mica, garnet, ilmenite, magnetite, perofskite, and in smaller quantities, hornblende, tremolite, cyanite, corundum and the diamond.[1] The blue-ground includes abundant fragments of rocks torn from the sides of the pipes during their formation, and varying in size from microscopic fragments to masses hundreds of feet across. These larger inclusions are commonly rounded, sometimes to such a degree as to have given rise to the erroneous impression that they had been derived from water-formed conglomerates.

In addition to the inclusions derived from the country rocks exposed in the workings there are boulders of intermediate, basic, and ultrabasic rocks, which have doubtless been brought up from considerable depths, as well as fragments which have fallen down into the pipes from strata which were at one time penetrated by the latter, but which have long since been removed by denudation from over the area in which the pipes occur. For example, at the Wesselton Mine the highest strata surrounding the pipe are shales belonging to the Dwyka series; but in the blue-ground there have been found [2] a lenticular mass of coal and two blocks of sandstone, one showing the remains of the fish *Acrolepis* and the other those of a reptile *Chelyoposaurus* allied to *Procolophon*.[3] This shows that the pipe must have penetrated the

[1] Carvill Lewis, *loc. cit.*; H. Harger, *T. G. S. S. A.*, vol. viii., p. 127, 1905.

[2] These statements have been denied by Voit in *Monatsberichten d. deutsch. geol. Gesellschaft*, 1908, p. 102; but have been verified by one of us in conversation with Mr. Jones, the finder of the inclusions.

[3] R. Broom, *Rec. Albany Museum*, vol. i., p. 184, 1904.

Ecca and Beaufort beds, strata no longer found in this part of the Colony. The blue-ground is thus seen to be a very heterogeneous material varying in character not only from one pipe to another, but in different portions of the same pipe.

A very peculiar property of the blue-ground is its tendency to crumble and pulverise after having been exposed to the action of moisture and the atmosphere for a short period. Certain portions, however, for some unexplained reason refuse to disintegrate, and have been given the name of "hard-blue" or "hardibank"; the constituent minerals in a hardibank are as a rule much less altered than in soft blue-ground. Hardibank is very much more common in fissures than in pipes, and this has led to the distinction of "fissure-kimberlite" from "pipe-kimberlite," employing the term kimberlite in its widest sense.

It is usually believed that the breccia now filling the pipes was intruded in the condition of a stiff mud, but the question of the temperature of the material at the time of its eruption is one that has given rise to a certain amount of controversy. It is certainly true that in the great majority of the pipes there is little or no sign of metamorphism either of their walls or of the inclusions in the blue-ground; on the other hand the effect of heat is very pronounced in other pipes, *e.g.*, Kimberley West and Paardeberg East, twenty-eight miles south-west of Kimberley.

It seems probable that the material forming kimberlite, at one time in a highly heated state, became rapidly chilled in its ascent in the pipes, so that different mines now record the effects of the eruptive breccia at different stages in its cooling.

As bearing upon the question of the origin of kimberlite, we must note certain basic and ultra-basic inclusions which are fragments of holocrystalline, and sometimes granulitic, rocks, derived probably from great depths in the crust of the earth. These rocks consist of various combinations of the minerals olivine, enstatite, brown mica, garnet, and more rarely ilmenite, felspar and cyanite. They can conveniently be termed peridotites, although certain combinations have been given special names, *e.g.*, eclogite, typically composed of chrome-diopside and garnet; saxonite, of olivine and enstatite; and lherzolite, of olivine, diopside, enstatite and garnet.

By some geologists these inclusions have been regarded as "concretions" or "segregations" which have formed in the magma of kimberlite during or prior to its solidification, but there are numerous weighty objections to this view. Thus they are sharply defined from the enclosing blue-ground and their boundaries are not formed by the faces of their constituent minerals. Again, they are holocrystalline, and are sometimes foliated and show the effects of dynamo-metamorphism. Further, the eclogites, for example, can be shown to belong to a peculiar group of rocks varying extremely in composition and known as granulites,[1] and having nothing in common with kimberlite.

The minerals and mineral fragments may be divided into three distinct groups according to their source,[2]

[1] *G. C.*, xiii. [2] *G. C.*, xi., p. 151.

excluding those that have been formed by alteration subsequently :—

(*a*) Tremolite, hornblende, epidote, orthite, tourmaline, rutile, muscovite, biotite, apatite, and possibly zircon.

These have evidently been derived from granite and gneiss, actinolite-schist, and probably also from inclusions in the granite.

(*b*) Olivine, enstatite, chrome-diopside, garnet, brown mica, occasionally ilmenite, magnetite and chromite, more rarely hornblende, spinel, sphene, cyanite, sapphire, graphite and the diamond.

These minerals have probably been derived from the basic and ultrabasic holocrystalline (and sometimes granulitic) rocks ; the most noticeable feature in this list is the absence of perofskite and the very infrequent occurrence of iron ores ; the diopside, too, is usually a different variety to that included in (*c*).

(*c*) Olivine, diopside, enstatite (?), brown mica, magnetite, ilmenite, apatite, perofskite, and melilite (Matjesfontein, Sutherland). It seems that these minerals can with a considerable degree of probability be ascribed to an eruptive magma which solidified during its ascent in the pipes and incorporated in its mass certain of the minerals of the groups (*a*) and (*b*). This eruptive matter is represented by certain brecciated fragments and occasionally by narrow veins in the blue-ground ; in these forms it is free of any foreign inclusions and shows porphyritic crystals of olivine, diopside, mica, and possibly enstatite, set in a serpentinous ground mass crowded with little crystals of perofskite, apatite and iron ores. In some cases it is markedly vesicular. It is, therefore, an ultrabasic rock and appears to be very closely allied both to the limburgites and to the melilite-basalts.

Much of the Kimberley blue-ground, indeed, contains porphyritic crystals of olivine, so that Carvill Lewis was led to regard it as a true igneous lava and not as a mud or ash, but it seems more justifiable to look upon the contents of the pipes as breccias derived from the explosive disintegration of bodies of ultrabasic lava; another effect of the explosions was to break up more or less completely certain basic and ultrabasic holo-crystalline rocks and to throw the rock and mineral fragments thus obtained up the channels opened by the explosions mingled with the lava in a plastic or solid state. In the upper portions of the pipes this eruptive material received further additions from the walls, and there appears to have been a great amount of stirring up and mixing of the heterogeneous mass. Not only do we find material obviously derived from great depths, but, on the other hand, in the deepest workings of the Kimberley Mine, more than 2,000 feet below the base of the Karroo formation, fragments of Karroo shale form an abundant constituent of the breccia.

The occurrence of the diamond as a constituent of some of the breccias has been the cause of far wider interest in the pipes than would otherwise have been the case. For many years the diamond was thought to have originated by the crystallisation of carbon derived from the carbonaceous shales surrounding the pipes, the mines of the Kimberley group being at the time the only examples known. Ultimately this hypothesis proved untenable, and the discovery of well-crystallised diamonds in the garnets of an eclogite from the Newlands Mine indicated that the gem was a primary constituent of certain holocrystalline rocks which are in all probability deep seated.

Since then diamonds embedded in single garnets or in the garnet of an eclogite have been found in several other mines, and the views of Prof. Bonney[1] have thus received considerable support.

Diamonds have not yet been found in the lherzolites or other ultrabasic rocks of South Africa, and it is doubtful whether such rocks are at all closely related to the eclogites. The diamond has, however, been discovered in a peridotite plug or boss in Arkansas[2] and in a diabase dyke near Inverell in New South Wales;[3] whether the gems crystallised out of the material in which they were found, or whether they were derived from some deep-seated rock cannot yet be decided.

It seems not unlikely that the diamonds found in the blue-ground have reached the places where they are found owing to the explosive disruption of certain diamond-bearing rocks, some of which were eclogites. The frequent occurrence of portions of fractured diamonds in the breccia is noteworthy as indicating that the gems did not crystallise from the molten magma of kimberlite.

There is great variation in the character of the stones

[1] T. G. Bonney, *G. M.*, 1899, p. 309.

[2] G. Kunz and H. S. Washington, *Trans. Amer. Inst. M. E.*, No. 20, 1908, p. 187.

[3] T. W. Edgeworth David, *Congrès Géolog. Internat.*, p. 1201, 1906, Mexico.

in adjacent mines or even in different parts of the same mine. The extremely high proportion of pipes in which diamonds are either scarce or entirely absent leads one to the conclusion that the presence of the diamond in the blue-ground must be regarded as almost accidental; it also shows that the parent rock of the diamond must be rather sparingly and unevenly distributed in the earth's crust.

Some geologists, however, still incline to the view that the diamond has crystallised out of the kimberlite magma itself; they consequently regard the eclogites as segregations from the eruptive material.

The alteration of the breccia after its intrusion into the condition known as blue-ground was most probably accomplished by ascending heated waters. The olivine and enstatite, more especially the former, and also, but to a lesser degree, the diopside, have been changed into pale greenish serpentine together with a small amount of calcite and iron ores. At the same time apophyllite, natrolite and other zeolites have been deposited as crystals accompanied by calcite, barytes, pyrites, and marcasite.

From the foregoing description of the breccias and other rocks filling the pipes and fissures we see that though they may differ widely in composition and character, yet there are usually to be found connecting links between one type and another.

Had the Spiegel River melilite basalt (alnöite) been the only example of this type of rock known in the Colony it would have been rash to have postulated any connection between it and the contents of the Kimberley pipes; but the association of the melilite-basalts of Sutherland Commonage and Matjesfontein in the same pipes with breccias containing some of the characteristic minerals of kimberlite, and their occurrence close to the Silver Dam vent, which is filled with an agglomerate still more like typical kimberlite, render the supposition much less improbable. The occurrence in the latter of various granulites of the same types as those of the kimberlite pipes is another important point of resemblance. In the remarkable agglomerates of the Saltpetre Kop group of pipes we find that though the bulk of the rocks is composed of the *débris* of sedimentary beds, yet there are also numerous fragments of the biotite, ilmenite, and hornblende characteristic of the Silver Dam breccia. Moreover, in Prieska (Grenaat Kop, etc.) pipes and fissures of the Saltpetre Kop type are found intimately associated with dykes of kimberlite and ultrabasic lamprophyre. Finally, no pipe or fissure belonging to any of these types has been found to be earlier than the Karroo dolerites, for inclusions of the latter rock are extremely common in all of them, indeed in some of the kimberlite pipes from 80 to 90 per cent. of the inclusions are of dolerite.

Reverting once more to the question of the petrological affinities of kimberlite, the opinion of Carvill Lewis may here be cited: "the abundance of calcite as a decomposition product, the high magnesia and low alkali, the presence of biotite, and more especially of perofskite, point to the possible presence of nepheline or melilite in the ground mass".[1] He therefore suggested

[1] Carvill Lewis, p. 49.

that the rock may have been a melilite-basalt, melilite being a mineral that is very prone to alteration; it has already been remarked that the character of those portions of kimberlite which are free from inclusions certainly favour such a view.

It is most interesting therefore to find that dykes of a rock indistinguishable from kimberlite have been found at two localities in North America, at Syracuse (New York) and in Elliot County (Kentucky),[1] and that in two dykes from the former locality melilite has been identified.[2] The intrusions contained in places numerous inclusions of sedimentary rocks and fragments of granite.

Lately several interesting dykes have been found in Prieska and Britstown which belong to the ultrabasic group of the lamprophyres; some contain abundant biotite, others augite and ægerine, while one has a base composed of analcime and is therefore very closely allied to the rock known as monchiquite. Fragments of lamprophyres of similar types have also been found in fissures and pipes containing kimberlite.

Although all these occurrences differ much in character and some varieties are occasionally found to be cut by others, there can be no doubt that they all belong to one period of volcanic activity. No direct evidence of their age is obtainable, but, as already mentioned, they are later than the Karroo dolerites; this is not only the case with the kimberlite pipes but with the Matjesfontein

[1] Carvill Lewis, p. 58.
[2] Smyth, *Am. Journ. Sci.*, xiv., 1902, p. 29.

Silver Dam and Saltpetre Kop pipes as well. We have already seen that the Karroo dolerites are posterior to the Stormberg vents and volcanics, therefore the period of activity represented by the kimberlite and other pipes is later still, *e.g.*, not earlier than the Lower Jurassic. If the resemblance of the Spiegel River melilite-basalt to the similar rocks of Sutherland be considered as evidence of their belonging to one and the same phase of volcanic activity, as in our opinion it may be, then the earlier limit of the pipes is advanced from Jurassic to Neocomian or post-Neocomian times.

It is worth while mentioning the fact that the other known African rocks containing melilite and having a distinct, though perhaps not very close, resemblance to the Colonial melilite-basalts occur in East Africa at Doenyo Ngai, Makinga Hill and Mount Elgon.[1] The East African rocks, however, are of quite recent date.

The Zuurberg Volcanic Fissure.[2]

A fault with southern downthrow separates the Uitenhage beds from the older rocks to the north in the Divisions of Alexandria and Uitenhage. The whole extent of this fault has not yet been examined, but from the Mission Station at Enon for a distance of nineteen miles eastwards a remarkable group of lavas, breccias and tuffs occupies a position along the fault. This volcanic

[1] Short descriptions of these rocks are given in Zirkel, *Lehrbuch der Petrographie*, 2nd edition, vol. iii., p. 25; Rosenbusch, *Mikroskopische Physiographie*, etc., p. 1276. G. T. Prior has described the Mount Elgon rocks in *Min. Mag.*, 1903, p. 228.

[2] For more detail see *T. S. A. P. S.*, vol. xvi., p. 189, and *G. C.*, x., pp. 34-42.

belt is not more than 100 yards wide where the road from Coerney to the Zuurberg crosses it, but it swells to nearly a mile on the east, where tuffs and breccias play an important part in its constitution, and it also widens out to the west of the Zuurberg Road. The belt terminates bluntly towards the east on the farm Duncairn, but its western end is not yet known.

The most important rock in it is a lava of a basaltic type, red in colour, and made up of a once glassy base in which lie crystals of labradorite, augite and olivine, but the last-named mineral is present in a quite small proportion. The glassy base is usually opaque in thin sections under the microscope owing to the amount of hydrated oxide of iron in it. Much of the rock was vesicular, but the steam-holes have been filled with various minerals, of which calcite, heulandite and chalcedony are the most striking. This basalt is not quite like the known volcanic rocks in Cape Colony, but it resembles some of the Stormberg lavas more closely than any other.

The breccias contain fragments of quartzite which may have been derived from the Witteberg beds; these fragments are set in a matrix of sharp-edged quartz grains and minutely divided indeterminate matter; felspars of kinds that occur in granites are also present, but they are a much less important constituent than quartz. The breccia from several spots is a buff-coloured rock, very similar to the matrix just described, but with fewer grains of quartz and somewhat darker in colour. Fragments of the lava do not occur in these breccias.

The tuffs are fine-grained rocks of very various colours, white, brown, green, yellow and red. The white, brown and yellow varieties are chiefly composed of quartz grains in a very fine ground mass; a green chlorite, probably derived from another mineral by alteration, gives the colour to the green tuffs, which are otherwise like those just described. The red tuffs contain much comminuted lava of a kind similar to the more glassy varieties seen in this volcanic belt. These lava fragments are very small, too small to be distinguished without the aid of a lens.

The lava frequently encloses pieces of tuff, and small vein-like dykes of lava penetrate the tuff, which is distinctly hardened near the contact.

In the course of the known part of the volcanic belt there are three rather marked enlargements occupied by masses of breccia and tuff, which probably mark centres of explosive eruption.

From an inspection of a map of this volcanic zone it might be thought that the rocks composing it rest unconformably upon the Dwyka and Witteberg series of the Zuurberg Range and are either unconformably overlain by the Uitenhage beds or are separated from them by a fault. If the Uitenhage beds lay unconformably on the volcanic rocks one would expect to find fragments of the latter in the Enon conglomerate, but they have not been found. The most significant fact, however, is that the Witteberg quartzites are much shattered where they are seen immediately on the northern or upthrow side of the fault in contact with the Enon conglomerate east of the end of the volcanic belt and also where they are in contact with the volcanic rock itself. The shattering of the quartzites extends for about one hundred feet from the southern limit of the quartzite, and it recalls the remarkable brecciation which has taken place along the fault which forms the northern boundary of the outlier of Enon conglomerate in Baviaan's Kloof.[1] The breaking up of the rock along the faults seems to be more than can be accounted for by the friction of the moving masses of rock. The breccia in Baviaan's Kloof and along the Zuurberg fault is probably due to explosions along the fault planes, and in the case of the Zuurberg fissure the explosions brought to the surface great masses of breccias and tuffs, and these were followed by the rise of basaltic lava.

As to the date of these eruptions it can only be said that they took place after the Uitenhage beds were deposited. No trace of superficial outflows of lava or layers of tuff have been found; the volcanic rocks now form a line of foothills to the Zuurberg Range and have been cut down to a surface which is continuous with, and has been produced by the same agencies as, the smooth surface of Zuurberg itself. The occurrence of agates in limestones of Upper Cretaceous age near the Bushman's River has been recorded by Prof. Schwarz,[2] and it is possible that they may have been derived from the Zuurberg lavas.

[1] See Schwarz, *G. C.*, 1903, p. 132.

[2] In a paper "On the Alexandria Formation," *T. G. S. S. A.*, vol. xi., 1908.

CHAPTER XII.

TERTIARY AND RECENT DEPOSITS.

In many parts of the Colony there are accumulations of sand, gravel, alluvium, limestones, quartzites, and ferruginous rocks that belong to a comparatively recent order of things, and in some cases are to-day in process of formation. There is invariably a marked unconformity between those rocks and the strata upon which they rest, although it is not always easy to find a suitable exposure of the junction.

The age of these beds can only be determined by the fossils contained in them, though their position with regard to the present level of the sea and that of rivers near them is of considerable value in this connection. Up to the present time but few fossils have been collected from these beds, and of those obtained only a small number have been studied by palæontologists. It is extremely probable that some of these formations contain species of mollusca that are no longer living; others have yielded bones of mammals belonging to extinct species; but details which will serve as the basis of a chronological classification of these deposits are not yet available.

In the following account the deposits will be chiefly classified on lithological and topographical grounds, though where possible a chronological arrangement will also be adopted.

1. The Knysna Series.[1]

To the north-east of Knysna, in the area almost entirely covered by forest, there are thick deposits of sand containing layers of clay and lignite filling hollows in an old surface formed by the Table Mountain series. The lignite and the sand contain large masses of coniferous wood and some leaves. Though no definitely determinable fossils have been found in these beds the specimens obtained are quite different from any known from the Uitenhage series, and the incoherent nature of the deposits makes it very probable that they are of later age than the Cretaceous. On the other hand, the fact that they fill such deep hollows in the Table Mountain series, and have themselves been trenched to their base by the existing rivers, makes it impossible to regard them as recent, *i.e.*, as belonging to the time when South Africa was occupied by the present fauna and flora. It is likely, therefore, that the Knysna beds are of Tertiary age. The beds are exposed in railway cuttings, drives cut into the sides of kloofs, and shafts. Occasionally horizontal lamination can be detected in the fine-grained beds, but usually the sand is strongly false bedded or lies in thick layers without divisional planes; these portions have the appearance of wind-borne sand deposited on the land. The sand is red or yellow in colour in the upper part of the series, but lower down it becomes brown owing to the presence of

[1] *G. C.*, xiii.

much vegetable matter. A thin layer of conglomerate made of pebbles of the underlying Table Mountain series in a brown lignitic sandy matrix was found at the bottom of a shaft north of Park Station. The lignite occurs in several layers which in places have a total thickness of seventeen feet.

The beds must be rather over 200 feet thick in all, and they rise to a level of 1,300 feet above the sea between Mill Wall and Park Stations. There are other areas of reddish false-bedded sand at a much lower level, and these may also belong to the Knysna series.

Though but little is known of these rocks they have an important bearing on the geology of the south-east coast. They rest on the high-lying coastal plateau which rises to altitudes of 1,500 or 1,600 feet. It is unlikely that the sea has ever covered these beds, for in that case they would have been swept away during their emergence; it is also unlikely that they were deposited at the present level, for the lignite and associated sandy clay were probably laid down in lagoons which could hardly have been formed near the coast and also at a considerable height above sea level. So, assuming that the form of this part of the African coast has not been radically altered since the Knysna beds were deposited, they must have been uplifted relatively to the sea level.

2. The Older Gravels, Surface Quartzites, etc.

In many places in the southern part of the Colony on the coastal side of the Langebergen there are the remains of a plain covered with gravel, ferruginous clays, or quartzites, and standing at various heights up to 1,200 feet or more above sea level. These remnants can be seen in many parts of the country between the Houwhoek Pass and Port Elizabeth; as a rule the material forming them resists the weather better than the rock below, and they therefore appear as table-shaped hills with steep slopes, or fringe the mountains as terraces with more or less sharply scarped fronts. Looking over the country from one of these hills the conviction is borne in upon one that the now isolated patches were once continuous, and that they formed a gently undulating plain connected with the terrace that is at places a conspicuous feature on the lower slopes of the Langebergen.

The terrace on the mountain-side north of Zuurbraak is separated by the deep valley of the Buffeljagt's River from the gravel-capped plateau south of that place; the gravels are coarse and contain many pebbles and boulders of Table Mountain sandstone that must have come from the Langebergen, although the ground on which they lie is now quite cut off from the mountains by the deep valley. In this case the rocks underlying the plateau are mainly Bokkeveld slates, but on the west and east Uitenhage beds enter into its composition without altering the character of the plateau, in spite of the fact that the Uitenhage beds are more easily eroded than the Bokkeveld.

To the east of the Gouritz River the road from Herbertsdale to Hagel Kraal lies on a terrace stretching far to the south of the Langebergen, cut out of the Table Mountain, Bokkeveld and Uitenhage beds in different parts. This terrace is considerably cut up by the eastern tributaries of the Gouritz River, but it is not divided into a terrace and a plateau as is the case with the old Zuurbraak terrace; the unity of the whole is still preserved. The Nouga River has exposed admirable sections showing the terrace gravels lying unconformably upon the Uitenhage beds, which there have a moderate northerly dip.

To the north of the Langebergen both the terraces and the plateaux are well represented. The former can be seen from the roads to Oudtshoorn from Mossel Bay where they leave the mountains at Saffraan River (Robinson Pass) and Doorn River (Montagu Pass). The best example of a plateau in this district is the Tafel Berg, between the Waterval and Bok Kraal Rivers south of Buffel's Fontein, a wide table-shaped area that does not deserve the name of Berg. It is covered with gravels derived from the Langebergen, from which it is now separated by the Waterval River.

In the Oudtshoorn-Uniondale-Willowmore area there is a great development of high level gravels (see Plates XXIII. and XXIV.). The watershed between the Olifant's and Baviaan's Kloof Rivers is on one of them. The present rivers for the most part run in deeply eroded valleys cut down through the plateau gravels. The mountains of that district, the Kouga and Baviaan's Kloof Ranges, rise abruptly from the surface of the old plateau.[1]

[1] See Schwarz, *G. C.*, viii., and *T. S. A. P. S.*, xv., 1904, p. 43. Papers read at joint meeting of B. and S. A. A. A. S., 1905, vol. ii., p. 56. *American Journal of Science*, xxiv., 1907, p. 185.

North of the Zwartebergen the gravel-covered terraces and plateaux are almost as well developed as they are to the south of that range. Near Laingsburg the highly folded Witteberg and Dwyka beds have been cut to a common level by the Buffel's River and its affluents at a period when the main stream flowed some 300 feet

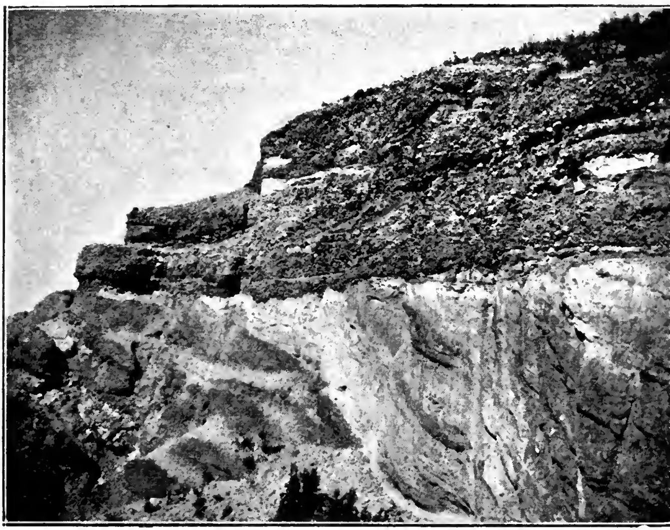


PLATE XXIII.—High-level gravels lying unconformably upon inclined beds of Uitenhage age (Enon type), Paarde Kloof, near Tover Water Poort, Uniondale.

above its present bed, and the surface of the terrace is strewn with gravel and alluvium. Similar features occur along the northern flank of the range at least as far as Prince Albert, where there are also some fine table-shaped and gravel-capped hills lying considerably to the north of the mountains.

In the neighbourhood of Grahamstown the gravel and quartzite terraces south of Botha's Hill and the curious Sugar Loaf Hill nearer the town are parts of a slightly undulating plain that has been cut into by the Blaauw Krantz River. The underlying rocks belong to the Witteberg and Dwyka series.

In the country north-east of the Gualana River, where the coast is formed by the Karroo formation, there are extensive plateau-like terraces bordering the coast, deeply cut into by the rivers flowing from the Stormberg and Drakensberg. At a few spots on the plateau that lies about 2,000 feet above the sea there are remains of deposits analogous to the old alluvium and quartzites of the country to the south-west. Kentani Hill is a conspicuous example of these. At the present time, however, little is known of the extent of these rocks.

In the Western Karroo a fairly well-developed terrace is visible along the foot of the Zwart Ruggens, the dry mountain ridge of Witteberg beds that limits the Ceres and Tanqua Karroos. In the Tanqua Valley a corresponding terrace covered with gravel derived from the Klein Roggeveld forms a conspicuous feature on the south side of the valley.

In all these cases the gravels are coarser near the mountains than farther away from them. Pebbles and boulders derived from the Table Mountain sandstone are by far the most conspicuous constituents in the high level gravels of the southern coastal region and in those of the country between the Langebergen and Zwartebergen. The boulders are sometimes of great size, four or five feet in diameter, and they have their edges rounded off; the smaller fragments are more rounded and are like the waterworn pebbles to be found in the modern stream beds. These fragments are embedded in a matrix that varies very greatly; in the bulk of the rock the matrix is a sandy material, but slightly hardened, from which the pebbles may be easily broken out; in other cases the matrix is deeply coloured by hydrated iron oxide, and the rock is in consequence reddish brown. Such ferruginous gravels are well developed near Genadendal in Caledon and at the foot of the Zwart Ruggens in the Western Karroo. Near the village of Napier there is a conspicuous kopje formed of a dark, highly ferruginous conglomerate, which probably belongs to the same group of gravels that are developed to the west of the village, at a considerable height above the bed of the Eland's Kloof River. The ferruginous cement has in many cases hardened the gravel to such an extent that the rock breaks across pebbles and matrix alike when struck with a hammer.

There is a gradual passage laterally from these ferruginous gravels to the fine-grained ferruginous rocks that lie farther from the mountains, and which often contain a few angular or subangular pieces of white vein-quartz derived from the slaty Bokkeveld or Witteberg beds underlying them. Magnificent examples of these hardened alluvial deposits are to be found in many parts of the Ruggens, forming rough-looking caps on the higher hills, such as Klaas Kaffir's Heuvel near the road from Swellendam to Bredasdorp.

The ferruginous rock is often directly underlain by white and yellowish clays, bleached by the slow removal of the iron they once contained which is now concentrated in the overlying rock. In some cases the traces of cleavage and joint planes are to be seen in the bleached material, which must then be regarded as a product of weathering *in situ* of slates; but most of the clays appear to be alluvial deposits formed by the rivers when they were at a relatively higher level than at present.

The ferruginous material is closely related to the laterites that occur at lower levels in many parts of the south-west, and which will be described on a later page.

Another very widespread variety of the gravels is due to the deposition of silica in the matrix subsequently to the formation of the gravel. All stages between a rather incoherent conglomerate and an extremely hard rock from which it is practically impossible to detach the contained pebbles can readily be found in one and the same patch of rock. The deposition of silica is most advanced on the upper surface of the mass, the lowest part of which is often a loose gravel. By the diminution in size of the pebbles and their gradual disappearance as the outcrops are followed away from the mountains the quartzitic gravels pass into the typical "surface quartzite" so widely distributed throughout the western and southern parts of the Colony (see Plate XXIV.).

As a rule the surface quartzites have certain peculiarities that enable one to recognise the smallest chip without difficulty; their fracture is smoother, more conchoidal, and less splintery than that of the quartzites of the older formations; small quantities of argillaceous matter, yellow or grey in colour, are present in the

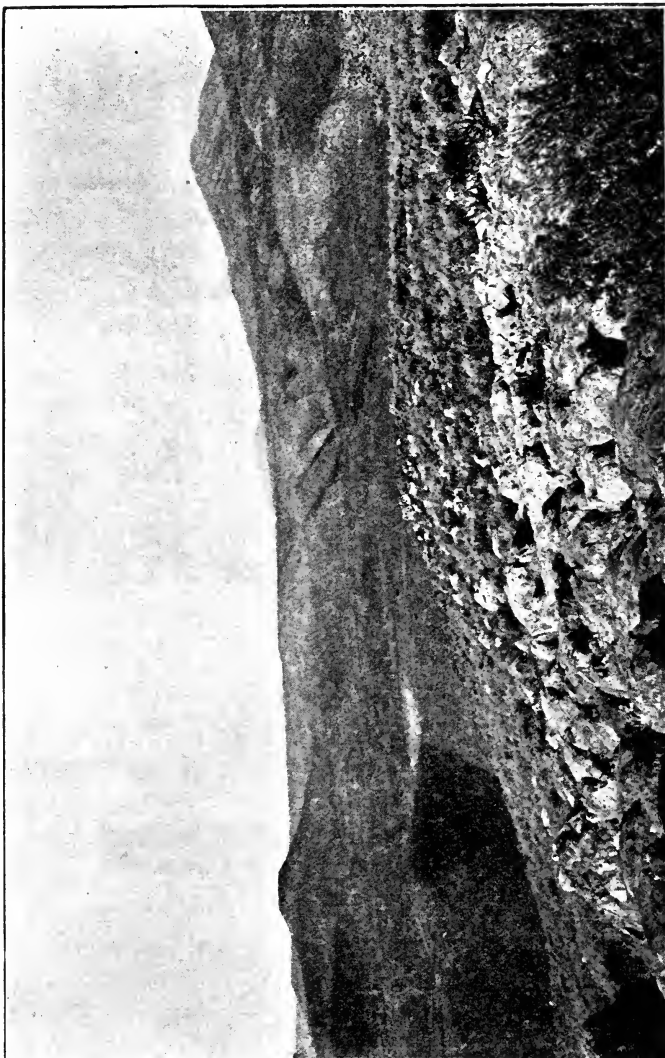


PLATE XXIV.—Gravel- and quartzite-capped terrace and outlier of the same; north side of the Kouga Mountains, near Uniondale. The rock in the foreground is silicified gravel.

siliceous matrix enclosing the grains of quartz that are often visible without the aid of a magnifying glass. The quartzites generally enclose many small irregularly shaped cavities, which are sometimes lined with minute crystals of quartz, or with the chalcedonic form of silica. The original quartz grains in the rocks are at places converted into bipyramidal crystals by the addition of new quartz in crystalline continuity with the quartz of the grain. By the mutual interlocking of the new quartz added to all the grains in the originally sandy portion of the rock, the loose sands have become intensely hard quartzites in which the original grains are no longer recognisable without the use of a microscope and thin sections of the rock, when the outlines of some of the grains can be seen within the new growth of quartz; the quartz deposited round any one sand grain interlocks closely with that round the neighbouring grains. Good examples of these quartzites may be seen in any of the south-western Divisions. They often appear above the soil as rounded polished surfaces, due to the weathering out of the rock along irregularly disposed vertical joints, which leave a massive lump of rock in their interstices. On the hilltop near the road from Swellendam to the bridge over the Buffeljagt's River the quartzite has been quarried for building purposes; the bridge piers are made of it. As a rule, however, the rock is too intractable and too variable within short distances to be worth quarrying, although it is certainly a very durable stone. Near Grahamstown the surface quartzites appear in the Sugar Loaf Hill and on the terrace to the north of it mentioned on a previous page.

The hard quartzite is at most ten feet thick, but the underlying soft clayey material, into which the quartzite passes without any definite break, is at places as much as forty feet thick.

The top of Kentani Hill, the only conspicuous elevation above the general surface of the plateau that stretches northwards from the Kentani escarpment, is formed by a hard quartzite, vitreous in parts, but usually with a rough pitted surface. The quartzite, which is only a few feet thick, passes downwards into variously coloured clays from thirty to forty feet thick.

A similar siliceous rock from a farm about nine miles south of Komgha village contains the silicified seeds of *Chara*, small spherical bodies with ribs passing spirally round them, and silicified shells of *Limnæa*. This is the only surface quartzite in the Colony known to contain recognisable fossils, but at present nothing is known of its extent.

On the Cape Flats there are several outcrops of surface quartzite, some of which contain plant remains that have not been determined. One well-known outcrop is near the main road to Stellenbosch about ten miles from Cape Town, and there are several others in its vicinity. The Cape Flats quartzites are usually whiter and more uniform in grain than the similar rocks in other parts of the Colony. The white colour is due to the almost complete absence of clay and ferruginous colouring matter; the quartzite passes downwards into a sandstone and that again into loose sand, which is identical with the white sand that occurs under the surface soil over a great part of the Flats.

In the Malmesbury, Piquetberg, Clanwilliam and Van Rhyn's Dorp Divisions surface quartzites are met with in many places on the coast side of the Olifant's River Mountains and the other ranges in connection with them. The quartzites are usually underlain by sandy clay or gravel into which they grade. By an increase in the amount of ferruginous colouring matter they become very similar to the laterites, and on the Van Rhyn's Dorp coast the latter pass into coarse conglomerates containing the shells of living species of

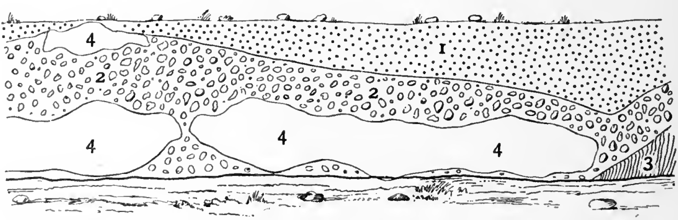


Fig. 29.—Section in cutting on railway close to Moorreesburg Station: 1. Sandy soil; 2. Clayey sub-soil full of ferruginous nodules and concretions; 3. Decomposed Malmesbury slates; 4. Quartzite masses. Length of section, 24 feet.

marine forms, raised beaches which lie from 50 to 100 feet above the high-water mark.

An interesting occurrence of these quartzites was exposed in a ballast pit on the down side of Moorreesburg station in 1905; it is illustrated by Fig. 29, which is drawn to scale. The quartzite forms flat masses, with irregularly curved surfaces, lying horizontally in a sandy and clayey ferruginous layer (laterite) under the soil or projecting into the latter. It is a bluish white rock made of angular chips of quartz and sand just like those in the laterite, cemented together by quartz; the outer zone, from $\frac{1}{10}$ inch to 4 inches thick, is ferruginous and brown in colour. The appearance of the rock gives one the impression that it was formed by silica replacing clay and iron oxides in the laterite, the fragments of quartz, derived from veins in the Malmesbury beds, remaining where they lay. No outcrops of the quartzite were seen in the neighbourhood, which is a plain very slightly above the level of a small stream bed a few hundred yards away.

This summary of the distribution and features of the high-level gravels and associated rocks shows that throughout the southern, western and south-eastern portions of the Colony there are gravels and alluvial deposits, altered to some extent by the deposition of silica and other cementing substances between the grains, lying high above the levels at which similar accumulations are being formed at the present day.

The origin of these gravel-covered plains has been attributed both to marine and to subærial erosion. Prof. Schwarz[1] has given reasons for believing that the parts outside the Cederberg-Langeberg Ranges were cut by the sea, but that the terraces and plains east and north of the ranges are due to river erosion at a time when the country as a whole stood at a lower level than now. The chief reason for postulating marine erosion for the outer plain was that it is difficult to understand how streams could cut such a uniformly narrow shelf as is found along the George and Knysna coast. It is difficult, however, on this view to explain the absence

[1] *Q. J. G. S.*, lxii., p. 70; *Geographical Journal*, March, 1906; *Am. Journ. Sci.*, vol. xxiv., 1907, p. 186.

of marine shells from so large an area of the gravels from the Knysna district westwards while they are so well preserved in the raised beaches seen in the Uitenhage district. The fact that on the coast of Van Rhyn's Dorp gravels with marine shells overlie, and apparently have been converted into, ferruginous and siliceous conglomerates,[1] does not imply that all the quartzitic gravels at much higher levels in the south and west of the Colony have suffered a similar change. The occurrence of the Knysna beds described in this chapter complicates the problem, but at the same time makes it improbable that the area in which they occur has been submerged since their deposition.

It seems more likely that the high level plains outside the mountains, as well as those within, have been cut by rivers, and that their dissection is due to their subsequent elevation and the downward cutting of the rivers. The raised beaches at heights of 100 feet or more above the sea may represent the shore deposits that were formed at the same time as the plains farther inland.

In the country north of the Orange River surface quartzites have a wide though far from uniform distribution. In Griqualand West they have only been recorded from a few spots on the eastern flank of the Langebergen.[2] In Bechuanaland, on the other hand, they are widely distributed at least as far west as Kuis on the Molopo, but they have not been found on the Kuruman River below Tsenin, the Mashowing below a point a few miles from Madebing, on the Hygap, nor

[1] *G. C.*, viii., p. 161. [2] *G. C.*, xi., p. 74.

in any of the pans yet examined in Gordonia, though they are a marked feature in Heuning Vlei in Bechuanaland and Waterpan in Vryburg. No explanation of this peculiar distribution has been offered.

These northern siliceous rocks fall in two distinct classes,[1] those which consist of grains of quartz and other minerals cemented by a siliceous matrix without evidence of the latter having replaced calcareous matter, and those siliceous rocks which bear evidence of having been originally calcareous, the whole or part of the calcareous matter having been replaced by some form of silica. The latter class of rock is by far the more abundant of the two in the north of the Colony, and as they always occur in intimate association with the surface limestones they will be described with the latter.

To the directly silicified rocks belong the outcrops on the eastern slope of the Langebergen at Paarde and Roodeman's Kloofs, the quartzites along the Genesa Laagte,[2] and some of those along the Molopo in Mafeking.[3]

3. The Newer Gravels and Alluvial Deposits.

At various levels between the high level deposits just described and the beds of the present rivers in the southern, eastern and western parts of the Colony there are more or less well-marked terraces covered with gravels and alluvium. Several such terraces can be

[1] These coincide with the two broad divisions of "eingekieselte" and "verkieselte Gesteine" of Prof. S. Passarge, in *Die Kalahari*, 1904, a very important book dealing chiefly with the geology of the Central and Northern Kalahari.

[2] *G. C*, xii., p. 109. [3] *Ibid.*, p. 149.

seen along the Breede River below Swellendam. It is often difficult to separate the higher of these from the high gravel plateaux, and hard ferruginous rocks and even quartzites may be found on them, but they may often be distinguished from the plateau gravels by the finding of pieces of the quartzitic or ferruginous gravels amongst their pebbles. The Breede River terraces have gravels containing such pebbles and boulders derived from the older deposits, originally of a similar nature.

In some parts of the Swellendam, Riversdale and Mossel Bay Divisions the gravels met with far from the mountainous ground often contain large pebbles derived from the conglomerates belonging to the Uitenhage series. These pebbles were well rounded, and were probably in much the same condition as they are to-day, before they reached their present position. The same is the case in other districts, such as Oudtshoorn, where the Uitenhage conglomerates occur. The abundance of these derived pebbles in positions where an explanation of their presence would be very difficult on the supposition that they were brought directly from the original source of the rocks of which they are made, is at places very striking.

Near the mouths of many of the rivers of the south and south-east coasts there are sandy deposits which extend to a considerable depth below the beds of the rivers. At the Bitou River[1] the green sands containing many marine shells, including large numbers of *Cryptodon globosus*, which is now comparatively rare in the adjacent sea, were pierced to a depth of forty-seven feet

[1] Schwarz, *G. C.*, iv., p. 61.

below the river without their base being found. The shells hitherto found in these sands and in similar deposits in other places all belong to existing species.

Test holes for finding solid foundations for a bridge across the Buffalo River at East London prove that the bed rock (the Beaufort series) lies at a depth of 122 feet below water level in the middle of the estuary, and that above it are over 100 feet of clay, sand and shelly beds.[1]

The considerable depth below sea level to which these estuarine deposits extend may point to a subsidence of the coast, but in some cases the scour of the river and tide combined are sufficient to account for the excavation of the estuaries. This certainly seems to be the case with the short but deep estuary of the Kaaiman's River, near George, where there is a rapid fall of the bed below the old road drift.

The alluvium along the great rivers draining the Great Karroo is often extensive and of considerable depth. It occurs chiefly behind mountain ridges through which the rivers have cut their way more slowly than in the softer ground now occupied by the alluvial deposits. A very good example is found in the Olifant's River (Oudtshoorn); this river rises south of Antonie's Berg in Willowmore, but it receives very important tributaries in the Traka, Meiring's Poort, Grobbelaar's and Kammanassie Rivers before it joins the Gamka in the middle of the Roode Berg mass of Table Mountain sandstone. The junction of these two rivers makes a great Y-shaped

[1] Schwarz and Chapman, *Rec. Albany Museum*, vol. ii., pp. 1-6, with a section and description of the ostracods and foraminifera, which belong to living species.

gorge, with vertical walls some 600 feet high, in the heart of the mountains. Before entering the gorge the Olifant's River runs for some eighty miles over flat country, and this tract is very rich in alluvium, especially below the junction of the Meiring's Poort stream. Underlying the alluvium there are rocks belonging to the Uitenhage group, which are soft and easily eroded compared with the Table Mountain sandstone. The mountains have acted as a check to the downward cutting of the river, that has consequently widened its valley behind them and deposited the alluvium to which the Oudtshoorn Division owes its wealth. These accumulations are gathered from nearly all the rock systems in the Colony, from the Pre-Cape rocks of the Cango to the Uitenhage beds of their immediate vicinity. The Gamka has formed a similar but smaller alluvial tract between Sand Berg (or Paarde Berg) and the Roode Berg gorge, and others occur lower down its course.

Another tributary of the Gamka, the Buffel's River, has cut a wide alluvial plain behind the Klein Zwartberg which it enters at Leeuw Kloof Poort.

Great tracts of alluvium are found along the rivers which flow northwards from the main watershed to the Orange River. The Fish, Rhenoster, and Zak Rivers in Sutherland, Fraserburg, and Calvinia, are especially rich in alluvial deposits derived from the Beaufort beds and the dolerite north of the watershed. Where water can be easily brought on to these lands they are extremely fertile. Tontelbosch Kolk in Calvinia, a farm on the banks of the Rhenoster, is perhaps the finest grain farm in the Colony. The fall of these tributaries of the

Orange is very slight compared with that of the rivers south of the main watershed; their valleys are more open, and towards their lower ends tend to disappear in the "vloers," the flat alluvial ground quickly flooded during storms but baked hard and drab a few hours later, that are a characteristic feature of the arid country south of the great river.

In the Western Karroo the rivers draining the Roggeveld escarpment receive a sudden check on leaving the Karroo formation and entering the region of the Witteberg beds, which are of a harder consistency. In the Bosch River Valley on Witte Vlakte a well has been sunk 140 feet through alluvium without reaching solid rock; this river has deserted its former channel, now marked by a very conspicuous poort in the beds west of the Poortje pan, and has turned southwards to enter the Draai Kraal's River several miles from its former point of junction.

The rivers of the west coast, from the Great Berg to the Olifant's, have considerable tracts of alluvium along the lower forty miles or so of their valleys. The Berg River alluvium extends to a depth considerably below sea level at many spots where wells give information bearing on the question.

Very little is known of the fossil contents of these river deposits, many of which are of quite recent origin, and therefore probably contain only the remains of living or lately extinct animals. The imperfect head of a gigantic buffalo,[1] *Bubalus baini* (Seeley), measuring eight feet six and a half inches between the horn-tips,

[1] Seeley, *G. M.*, 1891, p. 199.

although these are broken and therefore shorter than they were originally, is preserved in the South African Museum; it came from the Modder River, forty feet below the surface.

In 1906[1] the discovery of teeth of *Mastodon*, sp., *Equus zebra*, *Hippopotamus amphibius*, var. *robustus* (Fraas), and *Damaliscus*, sp. (allied to Bontebok), in the gravels of the Vaal River near Barkly West, was made known by Prof. Beck; though the fossils are fragmentary they prove the occurrence of *Mastodon*, which was not known before from any place nearer the Cape than Egypt. From the occurrence of the *Mastodon*, Drs. Beck and Fraas placed the beds in the Pleistocene.

4. Laterite.

In many parts of the southern and western coast districts there are layers of ferruginous rock resting either immediately upon the slates, granite or other rock of the vicinity, or with the intervention of a few feet of sandy clay. The underlying rock is usually considerably weathered, and sometimes bleached by the loss of its colouring matter, which seems to have been transferred to the ferruginous layer. The latter varies very greatly within short distances. It is usually a hard lumpy-looking rock, with innumerable small and irregular channels lined with a red-brown or yellow material. In places the hydrated sesquioxide of iron, limonite, is so free from sand and clay that it might be used as an ore; but generally there is a large quantity

[1] *G. M.*, 1906, p. 49, and E. Fraas, *Zeitsch. d. Deutsch. Geol. Gesellsch.*, 1907, p. 232.

of clay, sand and subangular fragments of vein-quartz and other rocks that do not decompose under the influence of the weather, cemented together by the iron oxide.

Along the edges of the Cape Flats near the high ground of the Peninsula and the Tyger Berg the laterite, or ironstone as it is usually called, is found a few feet below the surface. Farther inland, in the Malmesbury, Paarl, Caledon and other divisions near the coast, where there is no general covering of sand as on the Cape Flats, the laterite lies just below the soil, or is exposed at the surface, over considerable areas of flat and slightly inclined ground. It is rarely or never found in its typical form on steep slopes, although even in such situations the subsoil is in places partly cemented into a fairly hard substance by ferruginous matter, thus making an approach to the laterite of the lower ground.

The formation of the laterite is due to the concentration of the iron oxide near the surface in the decomposed rock or subsoil, occasionally in sandy soil that has been brought to its present position by water. The nature of the clay that accompanies the laterite in many places, especially where it lies upon clay slates, has not yet been ascertained.

The high-lying lateritic rocks are closely connected with the older gravels and alluvial deposits, and are now represented by mere remnants, but the low-lying ones are in process of formation to-day.

Very similar looking laterites appear to have been derived from rocks of diverse natures, such as granite and slate; even the Table Mountain sandstone of the west coast, Clanwilliam and Van Rhyn's Dorp, is in places covered with a ferruginous cemented material grading on the one hand into the raised beaches of that coast and on the other into the surface quartzites. Near Strand Fontein, a few miles south of the Olifant's River mouth, the almost flow-like appearance of the remains of the dark limonitic quartzite lying on the Table Mountain sandstone and filling up the open joints at various levels from that of the high tide to 200 feet above it has given rise to the idea amongst the people in the neighbourhood that it is lava. This somewhat remarkable variety of the lateritic rocks is certainly due to the deposition of the hydrated iron oxide, leached out from the underlying sandstones, between the sand grains which reached their present position through the agencies of wind and water.

5. Sand.

Extensive areas in various parts of the Colony are covered to a more or less considerable depth by sand. These deposits of sand may be roughly divided into two groups; those formed inland and those near the coast.

The inland sands are chiefly developed in the north and north-west. The largest area is in Gordonia and Bechuanaland, the southern end of the great sandy country called the Kalahari. Thousands of square miles are deeply covered with reddish or yellowish sand largely made up of quartz grains with a small quantity of felspar and other minerals. The red colour is due to a thin coating of oxide of iron, which disappears when the sand comes to lie in places where it occasionally remains wet for some time, as in pans and the beds of rivers.

The most remarkable patch of white sand in the country is at Witsands,[1] west of the Langberg in Hay; the sand there is pilled up round ridges of quartzite, and in low-lying spots between the sand-hills water is found a few inches or feet below the surface according to the length of time since the last heavy rain. In the sand there are banks of laterite, occasionally exposed through the removal of the sand by the wind. This laterite presumably represents the iron oxides leached out of the sand and deposited again near the surface.

The sand in a large part of the Southern Kalahari forms long dunes which may run parallel for more than a mile or may converge and join together; their trend is between west-north-west and north-north-west,[2] but near the river beds the dunes tend to lie parallel to them, and they are also banked up parallel to parts of the edges of pans.

At the present time the sand in the Southern Kalahari is kept in its place by grass and other vegetation; bare sand is rarely seen away from the waggon tracks. The largest areas of unprotected sand, which is then easily moved by the wind, are along the Orange River, where the veld is most rapidly eaten off by stock.

The average depth of the sand is not even approximately known. In the western part of Gordonia, where the underlying rock is frequently exposed, the dunes are often over 100 feet in height. In the eastern part of

[1] *G. C.*, xi., p. 72. [2] See Map attached to *G. C.*, xii.

Gordonia and in Bechuanaland the surface of the sandy country is often flat or very gently undulating over large areas. At Pepani, a few miles south of Morokwen, a well sunk on flat sandy ground penetrated 130 feet of loosely consolidated sand with a few hard lumps formed by the cementation of the sand by opaline silica, and two other wells on the same farm passed through 50 and 130 feet of sand respectively. Even if the moderate figure of 20 feet be taken as the average depth of the sand in Gordonia and the west of Bechuanaland the whole amount is very great. The chief source of the sand is undoubtedly to be found in the hills which formerly existed there and which are now in part represented by the isolated ranges in the South-Eastern Kalahari, such as the Scheurbergen, Korannaberg, Langebergen and the Heuning Vlei Range. The amount brought down by rivers from outside the region, the Molopo, Nossob and Kuruman Rivers, was probably small compared with that produced in the district itself. At the present time the products of denudation in this region are not removed by rivers, the wind is the only agent of transport, and probably the amount blown away is counterbalanced by that brought in. At some former period the sand seems to have been freer to move about than now, for it seems unlikely that the great dunes which are now covered with vegetation could have been formed under conditions in all respects like those of to-day.

In Prieska the granite, gneiss and mica-schist areas are usually covered with sand. A well-defined and narrow belt of red sand dunes extends up the Olifant's

Vlei River (near Van Wyk's Vlei) in a south-easterly direction becoming wider and spreading out in Victoria West. Patches of heavy red sand are common in Britstown, Hopetown and Kimberley.

In Bushmanland (parts of Namaqualand, Calvinia and Kenhardt) the sand is derived from the minerals composing the gneissose granite that occupies such wide areas there. Quartz and felspar are the chief constituents, and by the breaking up of the granite under the influence of the great diurnal change of temperature, one of the climatic features of that region, the minerals are set free to be carried about by the wind and rain. The sand is pink owing to the abundance of red felspar, and also to the iron oxide derived from the ferruginous constituents of the igneous rocks, biotite, hornblende, hypersthene and magnetite.

In the district between the Olifant's River mouth and the Berg River, as far inland as Piquetberg and the Olifant's River Mountains, there is a great quantity of sand. The country is known locally as the Sand Veld. The underlying rock is chiefly Table Mountain sandstone, although the southern part of the area is probably underlain by the Malmesbury beds. The whole area is characterised by a remarkable scarcity of running water and even of definite stream beds, although the southern part at least has a fairly heavy rainfall; the northern portion is much drier, but the absence of stream beds is due to the rapidity of absorption of the water by the ground and not to the lack of rain. From the Berg River to the Olifant's, a distance of some seventy-five miles in a straight line, there are only five stream beds to be found: the Zout, Verloren Vlei, Lange Vlei and Jackal's Rivers and the Zand Leegte. The Zand Leegte is a very well-marked valley about twenty miles long, commencing near Konaqua's Berg and terminating on the coast at Strand Fontein. The lower part of the valley is almost a gorge, some 180 feet deep, and at places only a few yards wide at the bottom, cut out of the hard Table Mountain sandstone. No water has been known to flow down this valley during the period covered by tradition in the district, perhaps 150 years, although a severe thunderstorm sometimes—about once in fifteen years—makes a stream of short duration in its upper part. The valley is being filled in with sand chiefly brought there by the wind. It is decidedly a striking proof that the district is drier now than it was at no very remote period, for there is no doubt that the valley was cut by a stream, and it was made since the advent of the still-living species of mollusca; for at the mouth of the gorge a raised beach lies about 100 feet above sea level, and appears to have stretched across the ravine; the raised beach contains the shells of mollusca of the same species as those found on the modern beach in addition to the water-worn pebbles and boulders that make a conspicuous feature on the top of the cliffs.

The evidence afforded by the Zand Leegte will explain the development of the Sand Veld. The tops of the sandstone hills still project above the sand, but the old valleys, that were carved out by rivers before the climate became as dry as it now is, are almost entirely filled up by the sand derived mainly from the sandstone hills and from the mountains built of the same rock to the east of the Sand Veld. Where exposed to constant sifting by the wind the sand is white or very light-coloured, but throughout the greater part of the area it is reddish. The red colour is certainly due to oxide of iron, but the source of the iron is not so evident. In sinking wells it is found that the lower layers of sand are paler in colour than those near the surface; it may be that the rain water, with the aid of organic compounds taken up during its passage through the soil, dissolves the iron oxides deep under the surface and brings them in solution to the top where it leaves them as thin films round the sand grains on evaporation. But it is possible that the very fine red dust brought into that part of the country by the strong east winds will account for the red colour of the surface sand. The fertility of the Sand Veld is remarkable, considering the general appearance and nature of the soil, good grain crops being obtained when average winter rains fall; it is probable that the wind-borne dust adds the necessary constituents to the otherwise extremely poor soil.

The Sand Veld sand passes somewhat abruptly into the dunes that line the west coast. The proximity of the coast makes itself noticeable by the increase of calcareous matter in the sand; the carbonate of lime is derived from marine shells which are pounded to dust on the shore and then blown inland.

Patches of sand dunes of greater size than usual are found south of Saldanha Bay, on the shores of False Bay whence the sand has invaded the Cape Flats, near the Bot River mouth, at Cape Agulhas, Cape Barracouta and Cape Recife. These are calcareous sands composed of a mixture of broken shells and fragments of minerals, chiefly quartz. The strong winds and constant supplies of fresh sand, as well as the facility with which the dune sand is moved, account for the difficulty of getting vegetation to gain and maintain a footing on these sand areas, which are a source of danger to the farms behind them.

6. Limestones of the Coast Belt.

The calcareous sands of the coast belt pass into limestone by the solution of carbonate of lime from parts of the mass, and its deposition near the surface when the water evaporates. In almost any part of the south-coast dunes a thin hard crust can be found covering sand which has been protected from the wind for some time; it may be less than a quarter of an inch thick, and is easily broken. By the long-continued deposition of the carbonate of lime the sand dunes are converted into hard rock through a distance of many feet from the surface, and where repeatedly wetted and dried, as happens when the sea has encroached upon old dunes, the rock becomes intensely hard and weathers with a peculiarly jagged surface. This material sometimes makes a good building stone (see chapter xiv.).

False bedding is a very marked feature in many sand dunes, being perhaps better developed in wind-borne accumulations than in sediments deposited under water. Magnificent examples of this structure can be seen in several cliff sections through the hardened dunes on the south coast between Cape Agulhas and Mossel Bay, and again to the east of Algoa Bay.[1] Plate XXV. is from a photograph of a cliff near Struys Point on the Bredasdorp coast.

In addition to the usually fragmentary remains of marine shells the dune limestones contain many fossils of animals that lived upon land, and these are in a much more perfect condition than the former. Snail shells, especially a large species of *Helix* that is commonly found living near the coast, are abundant in the limestones of Saldanha Bay and the south coast. Mammalian remains are frequently found, and they include species such as the elephant, rhinoceros and eland, that are no longer living in the neighbourhood. In the loose, scarcely consolidated calcareous sand of the Darling coast the remains of *Bubalus baini* and an extinct species of *Equus* have been found together with the remains of the rhinoceros and eland.

In the Bredasdorp Division there is a prominent range of dune limestone hills stretching from near the village to Cape Infanta.[2] In their western part the hills lie some twelve miles from the coast, and are separated from it by a tract of low ground; near the coast the country again becomes hilly owing to the modern dunes. The inland range must be of considerable antiquity, and it is now being destroyed by the weather and rivers without receiving any fresh material to compensate for this loss. A bore-hole 262 feet deep at Victoria Dale

[1] Atherstone, *Cape Monthly Magazine*, p. 273, 1858.

[2] For a more detailed description of these and allied rocks see *T. S. A., P. S.*, x., p. 427, etc., 1899.

Plate XXV.—False-bedded limestone near Struys Point, Bredasdorp.

was entirely in these limestones, and failed to reach the underlying formation.

These old dunes were formed at a time when the coast was at a lower level than now, during the period represented by raised beaches in several parts of the Colony.

The dune limestones are in places rather easily disintegrated, and weather very unequally, hence shallow caves are of frequent occurrence in them. At Cape Infanta there is a fairly large cave with a small entrance on the cliff; the roof is hung with stalactites, long tapering tubes of calcite deposited from the water percolating through the overlying limestone, and the floor is formed by a mixture of sand and bat-guano. The origin of the cave was probably due to a stream that no longer exists. This cavern is perhaps the largest (some 150 feet long and 20 feet high in parts) yet found in the dune limestones. Other caves of considerable depth, such as the Kellers near Danger Point, have streams of water still flowing through them.

7. Limestones of the Interior.

On the coast side of the Langebergen there is frequently a thin layer of whitish impure limestone immediately below the soil, and a similar rock covers wide areas in the western portion of Malmesbury and Piquetberg. The calcareous layer is especially well developed between the Kaffir Kuil's and Gouritz Rivers in Riversdale. There is a particular variety of the limestone seen in the soil about a foot below the surface that is now in process of formation. This is a nodular rock, rather compact, and it contains numerous sand grains and other particles derived from the soil. The calcareous matter collects together in certain spots and forms irregularly shaped lenticular lumps; neighbouring masses coalesce and produce layers. The bulk of the clayey material in the soil seems to be pushed aside by the calcite, but the sand grains remain behind. This rock is well shown in some of the railway cuttings between Heidelberg and Riversdale. It is similar to the "Kankar" of India.

In Northern Cape Colony thick calcareous deposits have formed in a similar manner below a covering of red sand.[1] Some of the calcareous tufas in the Orange River Valley, as in the neighbourhood of Hopetown, have been formed on terraces cut by rivers in former times.

The springs that come from the Bokkeveld series and from the Karroo beds frequently deposit a white tufaceous limestone which forms irregular layers in their neighbourhood, filling up the joints of the exposed rocks and cementing together the particles of soil. At the foot of the escarpment of the Kaap Plateau there is a great development of tufaceous limestone deposited through the agency of springs.

The sediments of the Karroo formation contain a fair proportion of carbonate of lime, and the dolerite which is so abundant in the form of intrusions in these beds contains about 10 per cent. of calcium oxide; this, on the decomposition of the dolerite, is chiefly converted into carbonate of lime. From these two sources the im-

[1] *G. C.*, xi., p. 126.

pure limestone that is so widely spread between the main watershed of the Colony and the Orange River has chiefly been derived. Every heavy rain that carries the products of decomposition from their place of origin to the flat ground, and especially to the shallow pans, brings with it some carbonate of lime which it leaves behind on evaporation. To this source must be added the slow creep of water towards the surface by capillary attraction and the influence of plants.

In the country north of the Orange River thick layers of limestone have been formed just underneath the surface.[1] They are best developed in flat country traversed by rivers draining the areas occupied by the Campbell Rand series, but they are not confined to such country. An interesting feature in connection with these limestones is that the carbonate of lime is replaced locally by silica in the form of opal and agate. The distribution of the silicified rock is peculiar; it has not been noticed on the Kaap Plateau, in the valleys running southwards from the Maremane anticline, on the Kuruman River below Tsenin, on the Molopo (Hygap) below its junction with the Nossob, along the western side of Gordonia, nor in any part of the country south of the Orange River; on the other hand the process has gone on between Vryburg and Tsenin and along the Molopo at least as far east as Kuis, and Dr. Passarge[2] has proved that silicified limestones of recent or late Tertiary age are found over an immense area in the Northern Kalahari.

[1] *G. C.*, x., pp. 202, 255; xi., pp. 69, 78, 126; xii., pp. 96, 187.
[2] *Die Kalahari*, 1904.

The origin of the limestones is to be found in the evaporation of water with carbonates in solution, just as in the case of the calc-tufa in the Karroo; it is more abundant north of the Orange River because the country there is flatter and more sandy than the Karroo, so that the sub-surface water moves more slowly and a greater proportion of it is returned to the atmosphere by evaporation, leaving the dissolved lime in the soil.

The explanation of the replacement of carbonates by silica, especially the peculiar distribution of the process in this country, is a very difficult matter. Dr. Passarge[1] says that the favourable conditions are an arid climate in a region of internal drainage followed by a period of greater rainfall; during the dry time alkaline carbonates and soluble silica accumulate in the ground, under wetter conditions the silica is dissolved and replaces limestone and is deposited as a cement between sand grains, giving rise to silicified limestones and quartzites. Deposition of silica at the surface is now taking place near Mossel Bay,[2] though the process is not understood, and from the fact that thin films of opal lie outside chalcedony lining cracks and small cavities in the northern limestones it is probable that silicification is still taking place there.

8. Raised Beaches.

At many places on the coast there are beaches of rolled pebbles, sand and shells at various heights above the present-day shore. These deposits frequently rest

[1] *Die Kalahari*, p. 618. [2] *G. C.*, x., p. 296.

upon a more or less extensive shelf cut into the sloping land behind the shore.

The most northern raised beaches yet found in the Colony are on the coast between the Olifant's River mouth and Thorn Bay. The coast is formed by a range of cliffs about 100 feet high, composed of the Malmesbury beds to the north of Strand Fontein and of Table Mountain sandstone to the south. South of the Zand Leegte the cliffs are remarkably fine, and they are broken into many small inlets and rocky points by the attacks of the Atlantic waves. The Table Mountain sandstone dips eastwards at about 35°, and is cut flat on the top of the cliffs. The old beach deposits lie on this flat surface, and consist of water-worn boulders mixed with sand. The beach has been cemented into a hard conglomerate by the deposition of iron oxides and siliceous matter in places, and in these conglomerates shells or fragments of them are scarcely to be found; but in other parts of the beach at the same level, where this process has not gone so far, shells belonging to species still living on the west coast are abundant, and the rock is a loose shelly conglomerate. Transitions from the latter to the former condition of the beach are to be found, and as the amount of change increases the shells decrease in quantity; they are dissolved without being actually replaced by the cementing material.

On the peninsula to the west of the south end of Saldanha Bay there are shelly limestones with abundant shells of living marine forms lying from ten to twenty feet above high water. These limestones pass inland into the hard dune limestone with land shells. They are an old beach formed when the land stood somewhat lower than at present. It is a curious fact that the dune limestone passes below sea level in Saldanha Bay and on the south coast; this rock on careful examination is always distinguishable from the calcareous beach deposits, and its occurrence below sea level in the same districts as the raised beaches points to a slight sinking of the land since the beaches were formed and elevated. At Kikoe's Vlei south-east of Saldanha Bay a bore-hole has proved the existence of superficial deposits down to a depth of over 50 feet below sea level.

In the Cape Peninsula there are a few patches of supposed beach deposits at a height of from 50 to 100 feet above the sea. They contain the remains of living species of mollusca. The Green Point Common is a fine example of a coastal shelf; a hard limestone containing shells occurs on it, at one point about fifteen feet above sea level.

In the neighbourhood of Hermanus there is a very well-marked rock shelf between the Klein River Mountains and the coast about fifty feet above the sea. It is a wave-cut terrace of Table Mountain sandstone, covered in places with dune limestone. Similar terraces are to be found near Danger Point, Zout Anys Berg and Pot Berg. At Cape Infanta there is a raised beach at the base of the dune-limestone, which there forms high cliffs. The beach conglomerate is about 100 feet above the sea. On the shores of Algoa Bay there is a well-developed terrace cut through the Uitenhage beds; it slopes gradually towards the sea from a height of about

400 feet above high tide in its inland portion to 200 feet where it is concealed under the blown sand of the coast. The shelf is covered in places with shelly conglomerates containing glauconite and the remains of mollusca still living off the South African coast. A characteristic shell in this deposit is a very large *Pectunculus.* At lower levels nearer the sea there are patches of old beaches which contain shells belonging to living species.[1] Many of these raised beaches contain numerous species of shells, and the careful collection and determination of these from the different deposits is certain to yield interesting results.

Although the evidence bearing on the question of a recent change in level of the whole coast line is so widely distributed much remains to be done before it can be fully understood. So far as it goes, it is in accordance with the presence of the river-cut high-level plains now deeply channelled by the existing streams. There is good reason to believe that while these plains were being made the higher raised beaches were also in process of formation. In the Swellendam Ruggens, for instance, the old gravel and alluvial plateau that slopes gradually towards the coast and is trenched by tributaries of the Breede River terminates at the foot of the Bredasdorp limestone hills, which we have seen were once calcareous sand dunes. These are continued into

[1] Descriptions of the occurrences will be found in Stow, *Q. J. G. S.*, xxvii., p. 497; Johnson, *T. G. S. S. A.*, vi., p. 9; Schwarz, *T. G. S. S. A.*, xi. A list of shells from a low-level raised beach near Mossel Bay is in *G. C.*, x., p. 293. Prof. Schwarz includes the beach deposits of Uitenhage and Alexandria with the Need's Camp beds (Danian) of East London in one group under the name of Alexandria formation.

the limestone that overlies a pebbly beach deposit at Cape Infanta, now being cut back by the sea. At the time when the inland plateau was being cut the dunes that now form the limestone range were being piled up by the wind, and the coast was indented by a broad bay between Cape Infanta and Bredasdorp village. The eastern corner of the bay extended farther seawards than the present position of Infanta, for the high cliffs made of Table Mountain sandstone in their lower part and of the beach deposit and limestones in the upper half must have been undergoing destruction ever since the raised beach was removed from the reach of the sea.

In the Algoa Bay region the high level gravels of the Zwartkops Heights were probably formed at the same time as the terraces covered with surface quartzites and allied deposits near Grahamstown, and the wide rock terrace traversed by the main road from Port Elizabeth to Humansdorp. The upward movement of the land which raised the Zwartkops Heights beach to its present level also brought about the renewal of the downward erosive power of the rivers inland, so that they trenched the gravel and quartzite plateau of Grahamstown.

9. Vlei Deposits.

Near their mouths many South African rivers expand into wide shallow lagoons. The larger rivers, such as the Berg, Breede, Gouritz, Kei and St. John's, which maintain open channels to the sea throughout the year, have comparatively small lagoons or none at all, although some of them, such as the Berg, give rise to shallow vleis beyond their banks in times of flood. The smaller streams whose mouths are more or less regularly choked up by sand bars terminate in vleis of various dimensions. The formation of a wide vlei in place of a sharply defined channel is easily understood; the water flowing into the lagoon cannot escape quickly, but filters slowly through the sand bar; it therefore stands above the sea level, and owing to its constant movement it laps against the usually soft sandy banks and gradually washes them away, depositing the *débris* in the deeper portions of the channel. The absence of an open mouth prevents the tide from assisting to keep the channel clear. The mud brought down by the river mingles with the sand blown or washed by rain into the vlei and makes a sandy loam, which tends to form a flat surface somewhat above sea level, so that should the mouth become open for a long period the river will flow through a flat alluvial tract just before entering the sea. Such may be the origin of the flats at the mouths of the Zwart Kops and of the Great and Klein Brak Rivers in Mossel Bay. The same feature is seen at the Kowie mouth, although in this case the channel is maintained by the walls built for the harbour. The Bot and Klein Rivers in Caledon and Bredasdorp have large vleis, which are only open after the winter rains. Many large lagoons, such as Zoetendal and Salt River vleis in Bredasdorp, have quite small rivers flowing into them, and are very rarely open to the sea. Zoetendal vlei is fed by two rivers, and near the mouths of one of them a small stream flows to the sea at certain times by a longer route than would be afforded by the vlei if it were open to the sea near Northumberland Point. In the Transkei and Pondoland very many small streams rarely bring down enough water to break through their sand bars, and in time they will form corresponding alluvial tracts with small channels traversing them. The comparatively recent elevation of the coast that enabled these rivers to cut deep valleys through the coastal plateau has not been of sufficient duration to allow them to silt up their lagoons.

A vlei is sometimes formed along the course of a river just behind a ridge of rock that is with difficulty cut through by the stream or behind a belt of sand dunes. The softer rock behind the obstruction allows the river to cut out a wide plain, and by the unequal distribution of *débris* over the plain the bed of the stream may be raised slightly above the level of the plain, causing the latter to be flooded at times. A process of this sort has taken place in the valley of the Bosch River where it approaches the Bokkeveld hills west of Witte Vlakte. An extensive vlei or pan, on the farm named Poortje, is the result, and the river has found an easier course to the south, where it joins the Draai Kraal's River.

Very extensive "vloers" are formed along the rivers entering the Orange River from the south, and are produced by the spreading out of the river course over a red clay flat.

The water that gathers in these river vleis is sometimes brackish from the salts derived from the soil; especially is this the case after it has been standing for some time.

10. Pans.

Of great interest are the peculiar depressions to which the name of "*Pans*" has been given. There are two classes of these; the first consists of the pans near the coast, the second of those lying far inland.

The pans on the coast are usually at a low level, separated from the sea by a belt of sand dunes. There are several of these on the west coast south of the Olifant's River. Rain-water collects in them, and owing to there being sufficient clayey matter or limestone round them the water does not drain away but evaporates slowly, leaving a thin crust of salts, mostly composed of sodium chloride or common salt. Usually the thin crust is not sufficiently free from sand to be used for domestic purposes, so shallow trenches are dug in the floors of the pans during the dry season and a deposit of salt three or four inches thick is formed in them after the rains. The salt is probably collected by the rain-water in its course through the surrounding sandy soil, which receives it gradually from the sea in the form of spray or attached to the grains of sand blown from the shore.

On the coast of Bredasdorp there are several productive pans. Some of them are within a short distance of pans which contain fresh or nearly fresh water only, yet no difference in the conditions of the salt and fresh vleis is observable. This fact is difficult to explain on the supposition that the salt is washed into the pans from the surrounding soil; but at no distant period the low-lying parts of the Bredasdorp coast must have been under the sea, or at any rate liable to inundations of salt water at high tide during storms, and it is possible that the salt derived from this source is still inexhausted in spots where, owing to a slightly lower level or to the presence of more favourable surface deposits, a larger quantity of the sea-water evaporated than elsewhere.

One of the best known salt-pans is that on the Zwartkops Heights north of the river of that name. It is surrounded by the shelly beach deposits described on page 406, but the fossiliferous clays and limestones of the Sunday's River beds crop out beneath them on one side of the pan. The salt which collects in the pan after rain must come from the rocks near at hand, probably from the Sunday's River beds, some of which contain enough salt to form an incrustation on their outcrops on the road leading to Addo Drift; so far as we know, however, the presence of salt in the beds round or under the pan has not been proved. Crystals of gypsum lie in the sandy mud on the floor of the pan.

The inland pans are abundant over a great stretch of country extending from the north of Calvinia through the Divisions of Fraserburg, Carnarvon, Kenhardt, Prieska, Britstown, Hopetown, Kimberley, and Boshof. This tract is sometimes called the Panne-veld and coincides roughly with the outcrops of the Dwyka series. Pans are also numerous in Gordonia on the same formation.

These pans are usually circular or oval, more rarely irregular, in outline; they vary from a few yards up to several miles in width. Haakschein Vlei in Gordonia is fourteen miles long and six miles wide; Kopjes Kraal

Pan in the same district is about nine miles long and five wide, while the Government's Pan between Strydenburg and Paauwpan Station is sixteen miles in length and about two miles across. Pans from one to four miles wide are very numerous.

The material forming the pan floor varies considerably in character. Sometimes it is a hard red clay a few inches in thickness; below this there is usually shale. More commonly the soil is drab in colour and somewhat porous; in some of the salt-pans it is so soft and powdery that one walks with difficulty over the surface; this character may be due to the effect of capillarity when the last traces of saline water are being evaporated by the solar heat. In some pans, especially in those situated upon the Pniel diabase, there is a powdery black soil, while if the underlying formation is limestone there may be a good deal of porous tufaceous limestone in and around the pan.

There seems to be very little reason to doubt that the majority of the pans have been excavated principally through the agency of the prevailing northerly or north-westerly winds. The bare soil in the pan becomes finely comminuted, and frequently quite a gentle breeze raises clouds of dust, while outside the pan the vegetation protects the ground to some extent and the sand is not blown back in considerable quantities because there are no suitable winds.

It thus happens that the southern and south-eastern edge of the pan is bounded by an area of fine light-coloured sand sometimes forming dunes. Nowhere can this be better seen than at the salt-pan between Douglas and Belmont. On the clay floors coarse sand cannot obtain a lodgment; this is proved by the breaking of the continuity of a long belt of north-westerly trending sand dunes by the Verkeerde Vlei pan near Van Wyk's Vlei. On the leeward side of the pan the width of the belt of dunes is more than twice that on the windward side. Another peculiar feature in connection with these pans is the fact that inblown red sand rapidly loses its colour, the bleaching being due to the removal of the ferric oxide forming a film round the sand grains or filling minute crevices in them.

The amount of the depression below the surrounding country is often very slight, but sometimes it may be as much as 200 feet. Several pans in Hopetown, namely Krantz Pan, Vogelstruis Pan and Roode Pan, are sunk abruptly, and the north-western rim in each case is a cliff capped with the calcareous tufa which covers the surrounding country. The origin of these escarpments, rising as much as 150 feet above the floors of the pans, is due to the weathering of the shales below the hard tufa and the transport of the disintegrated material by the prevailing wind to the opposite side of the pan.

Pans are found on practically every formation in the north, but they are most numerous in the Dwyka, and are abundant on the Ecca. In a large number of cases pans are due to the complete or more usually to the partial removal of the Dwyka shales and tillite from basin-shaped hollows in the Pre-Karroo surface, *e.g.*, Swingel's Pan (Hopetown); more frequently a ridge of hard rock is exposed on one side only, *e.g.*, the salt pan at Riverton. Pans may form on the junction of two formations, *e.g.*, along the boundary of the Black Reef and the Campbell Rand series in Vryburg; at the top of the latter formation at Heuning Vlei; and alongside a dolerite intrusion as at Strydenburg. Several pans in Gordonia are surrounded by sand and no rock is exposed within them. As far as can be judged the erosive action of the prevailing wind is the most potent factor in pan formation. Passarge[1] has, however, suggested that pans may have been deepened or even perhaps wholly formed through the agency of the vast herds of wild animals which not so long ago used to exist in Southern Africa. Mud was removed adhering to their bodies when they had finished drinking and wallowing, and at the same time substances contained in solution, chiefly carbonate of lime, were removed. The rainfall and sub-surface water gravitate into these depressions and there evaporate, so that in time there is a concentration within the pan of substances dissolved out of the surrounding soil and rock. Hence in the wet season the water in a great many pans is brackish or even salt, while in the dry season the floor of such a pan may be covered with a white saline incrustation. Such salt-pans are quite common in the Colony, and many of them have yielded vast quantities of salt without showing any signs of exhaustion. Rautenbach's salt-pan in Gordonia in three miles long and nearly a mile wide, and the incrustation of salt forms a solid cake from one to two inches thick lying on black sandy mud.

A most remarkable feature is that very often round

[1] *Die Kalahari*, chap. xvii.

the edge of a salt-pan, or occasionally even within it, fresh water can be obtained on digging shallow pits; a good example is the salt-pan in Herbert.

In a pan at Klip Fontein's Berg, in Clanwilliam, the depression, from which common salt is gathered for domestic purposes, is surrounded by a thick layer of carbonate and sulphate of lime. The sulphate of lime (gypsum) occurs in small and large crystals embedded in a calcareous, sandy mud, and it forms the larger part of the deposit. The material is well stratified, and the layers are thin.

Hot Springs and their Relation to the Structure of the Country.

Springs from which water issues at temperatures considerably above that of the air[1] are rather numerous in Cape Colony. Some of these yield water of much the same composition as ordinary spring water; the Brand Vlei, Olifant's River (Clanwilliam), and Montague

[1] Detailed information on the contents of the water from some of these springs will be found in Krauss, *Neues Jahrb. f. Min.*, etc., p. 150, 1843; Gumprecht, *Die Mineralquellen auf dem Festlande von Africa*, Berlin, 1851; Noble, *Official Handbook of the Cape and South Africa*, Cape Town, 1893; Daniell, *South African Medical Journal*, vol. ii., p. 242, 1895; Schwarz, *G. M.*, p. 252, 1904. The water of the Montague springs has been found by Dr. Hahn to be strongly radio-active. The temperatures of some of the springs are the following:—

Brand Vlei, 145° F.	Malmesbury, 88° F.
Caledon, 120° F.	Cradock, 86° F.
Olifant's River (Oudtshoorn), 114° F.	Koega, 79° F.
Montague, 112° F.	Aliwal North, 80° F.

These figures are taken from the papers cited; Dr. R. Marloth of Cape Town kindly gave us corroborative information concerning many of them.

springs are of this kind. The water from the Caledon springs contains much ferrous carbonate, and the Warm Water Berg spring water has a smaller quantity of the same salt in it. Sulphuretted hydrogen is a constituent of the Malmesbury, Cradock, and Graaff Reinet mineral waters.

The majority of these springs rise in Table Mountain sandstone areas, but their distribution is not connected obviously with the great dislocations or folds visible in that formation; there is no spring situated on or near the largest strike faults, those of Worcester and the Cango, nor does one occur in the more intensely folded portions of the east and west ranges south of the Karroo. The Olifant's River (Clanwilliam) hot-bath is on the eastern limb of the gentle anticline that forms the Cardouw Mountain; the hottest spring, that of Brand Vlei, is near the locality where the dip of the Table Mountain sandstone south of Worcester changes from north to east; the Caledon, Warm Water Berg, Montague, and Olifant's River (Oudtshoorn) springs issue from the sandstone on the flank or at the end of anticlines.

The Malmesbury spring flows from a mass of granite, and those of Cradock, Graaff Reinet (cold) and Aliwal North[1] from the nearly horizontal Karroo formation in the great interior basin. It is remarkable that the Malmesbury and Karroo mineral springs contain sulphuretted hydrogen, while the others do not. This gas, in small quantities, is given off by many of the ordinary springs in the Karroo, and is probably derived from the decomposition of pyrites. Whether the gas in the

[1] *G. C.*, ix., p. 78.

hot springs has a similar source is of course not known.

At Tarka Bridge[1] near Cradock saline water at a temperature of about 80° F. issues from four bore-holes. The most remarkable feature about them is the fact that the water rises and falls at twelve and a half hour intervals in a manner analogous to the oceanic tide. The bore-holes clearly draw their supplies from the same underground source, for the composition and temperature of the water is the same in each case, while the pumping of one hole affects the discharge from the others.

The probable reason of the high temperature of the springs is that the water comes from great depths. So far as one can judge from the surface geology none of the springs is in any way connected with volcanic action. Many of the older travellers took the dark slaggy-looking deposits of hydrated ferric oxide at Caledon for lava, but the dark rock is derived from the ferrous carbonate in the water by oxidation on contact with the air. In the Western Karroo there are several cold springs at the foot of the Zwart Ruggens that leave a similar deposit of limonite, but there is hardly sufficient iron in the water to make it taste unpleasant.

[1] Young, A., Papers read at the joint meeting of the Brit. and S. A. A. A. S. in 1905, vol. ii., p. 144.

CHAPTER XIII.

THE GEOLOGICAL HISTORY OF THE COLONY.

THE further back one looks into past times the more difficult it is, on the whole, to interpret the story concealed by the rocks of any country. The reason of this is that the older the formations are, the longer have they been subjected to forces which tend to bring about changes in rocks below ground and to sweep them away and deposit their fragments elsewhere when exposed at the surface; in the first case their original characters may be altered beyond recognition, and in the second they may be entirely removed over large areas.

In Cape Colony a very important class of evidence, that of the fossil remains of plants and animals, can only be brought to bear on the question at a comparatively late stage in the geological time-scale, *viz.*, the Devonian. In other countries the distribution of land and water can to some extent be made out by means of fossils from the Cambrian, Ordovician, and Silurian systems, which together represent a great period of time anterior to the Devonian.

In all the other continents, however, there are rocks older than the Cambrian whose characters show that they were formed under conditions not very different from those of to-day, and as yet these Pre-Cambrian beds have yielded no very definite fossils. In South Africa there is an immense thickness of unfossiliferous strata, the Pre-Cape formations, older than the Devonian system, but we are still in complete ignorance of the position of an horizon corresponding to the base of the Cambrian system of other continents. Hence such terms as Pre-Cambrian and Algonkian, which assume the recognition of a Cambrian fauna, should not at the present time be applied to any South African formation.

The earliest sedimentary rocks recognised in Cape Colony are the Malmesbury beds of the south and west, and the Kheis beds of the north; whether these two groups are in part of the same age is quite unknown, but they both represent the results of a long period of denudation and concurrent deposition; where least altered they are chiefly arenaceous and argillaceous rocks, and there are also some interbedded limestones. There is no rock in Cape Colony that has been shown to be older than these two groups of beds; we know nothing corresponding to the Archæan system of some countries, a formation whose origin is doubtful and which is older than the earliest recognisable sediments.

Both the Malmesbury and the Kheis series occupy wide areas and have high dips throughout, from which we may conclude that they were strongly folded and at one time formed very considerable mountains. At the present day the hills made of them rarely rise 1,000 feet above the surrounding country, and in some cases (*e.g.*, Signal Hill, Groenberg) the prominence of the hills is due more to the former existence of a protective cover of later rocks than to the resistance or structure of the older beds.

In addition to being crumpled up, the Malmesbury and Kheis beds were invaded by granite. From Cape Town northwards as far as the Moed Verloren hills in Van Rhyn's Dorp granite and gneiss are in places found in intrusive contact with the Malmesbury beds, and at present there is nothing to suggest that we are concerned with more than one period of intrusion. At Moed Verloren, beds which can without difficulty be assigned to the Malmesbury series are to be seen in contact with the southern end of the great north-western granite mass, which probably stretches through Namaqualand and Kenhardt to Upington. Our information about this great mass is at present rather scanty; it has been traversed in various directions by Wyley and Dunn, and from their maps and descriptions we get no hint that it belongs to more than one period of igneous activity. Should a more complete survey prove that the mass is one throughout, that conclusion will be of great importance, for at Upington the granite is intrusive in the Kheis series. Thus both the Malmesbury and the Kheis series may be older than the same body of granite.

However that may be, it is certain that the Malmesbury beds and the granite were subject to prolonged erosion before the Ibiquas, French Hoek, and the Cango series were deposited in the west and south; and in the same way the Kheis series and the northern granite contributed to the formation of the sediments of the Ventersdorp system and the Black Reef and later beds.

The three south-western formations mentioned above, Ibiquas, French Hoek, and Cango series, are alike in including conglomerates in which granite and slaty rocks are conspicuous, but there is not yet enough evidence to correlate the three of them. One of the chief features of the Cango series is the great development of dolomitic limestone, which probably represents a marine deposit.

Both the Wilgenhout Drift and Kheis series include limestones, and also contemporaneous volcanic rocks of acid and basic composition, which are found again in the Kraaipan series. These lavas and tuffs are the earliest volcanic rocks known in the Colony. After the formation of these three groups of rocks they were greatly folded and faulted.

At the present time the known distribution of the Wilgenhout Drift and Kraaipan series is very limited, but they doubtless formerly covered a very wide area. They probably formed great ranges in the north of the Colony, but their destruction was brought about during a long period preceding the deposition of the rocks of the Vaal River or Ventersdorp system. During this period of denudation the Witwatersrand system was deposited and again partly denuded away in the Transvaal. Whether that system is now, or was formerly, represented in Cape Colony is unknown; it has not been identified here. Its existence in the Transvaal adds very greatly to the already enormous length of time required for the successive deposition, folding, and denudation of the unfossiliferous rock groups of Cape Colony.

The Ventersdorp system has two unconformities within it in Cape Colony. The lowest member is the Zoetlief series, mainly lavas of acid composition which occur at various places in Hopetown, Griqualand West and Bechuanaland; this is followed unconformably in the T'Kuip hills by the Kuip beds, lavas and sedimentary deposits, arkose, cherts, limestones and flagstones. The Kuip beds are overlain unconformably in the T'Kuip hills by the Pniel series, the most widely distributed member of the Ventersdorp system. The Pniel series includes both volcanic rocks and sedimentary beds derived locally from the waste of older formations, but the most characteristic rocks in it are the diabase lavas. A remarkable feature is the varying thickness and occasional absence over wide areas of the sedimentary beds at the base of the group. This series of rocks is met with in many places from Morokwen and Mafeking southwards to Hopetown, and it also covers wide areas in the Transvaal, but it has not been definitely recognised in Gordonia. The Ventersdorp system records a long-continued period of volcanic activity, and perhaps the unconformities within the group were closely connected in their origin with the vulcanicity.

The rocks of the Ventersdorp system underwent a considerable amount of denudation before the basal member of the Transvaal system was deposited in Cape Colony, but it is certain that this unconformity is not of the same order of importance as the one at the base of the Ventersdorp system; it is rather to be compared with the unconformities within the latter. In Bechuanaland lavas like the Pniels are interbedded with the

Black Reef, or lie between the Black Reef and the Campbell Rand group, proving that volcanic activity, of the same kind as that which gave rise to the Pniel lavas, continued during the early part of the Transvaal period.

The significance of the Black Reef series, chiefly arenaceous beds which stretch from the north of Bechuanaland through Griqualand West into Prieska, is that it implies a general invasion by water at the commencement of the Transvaal period. In Bechuanaland and Griqualand West the floor on which this series rests seems to have been remarkably flat. The character of the sediments, ripple marked sandstones, conglomerate beds and flagstones is that of rocks laid down near land. The direction whence the invasion came has not yet been determined.

The Black Reef beds are followed conformably by a great limestone formation, the Campbell Rand series, which was very probably of marine origin. It is interesting to note that an unconformity implying local disturbance along a north-north-west axis of folding has been found in the Campbell Rand series in the south of Griqualand West (the Leij Fontein unconformity). The strata above and below the unconformity are alike; had they been dissimilar the phenomenon would have closely resembled the unconformities within the Ventersdorp system.

The beds of the Campbell Rand series maintain a constant character over a large part of the Transvaal and the north of Cape Colony as far west as the Korannaberg, therefore the sea must at that time have extended over that wide area. Should the opinion of Profs. Schenck and Passarge, that the dolomites of Namaland and the N'Gami country belong to this group, be correct, we shall have evidence of a still greater extension of this sea.

The Campbell Rand limestones are succeeded conformably by the Griqua Town series, the peculiar characters of which certainly indicate a complete change in the conditions of sedimentation, though it is uncertain how the change was brought about and what the new conditions were. Their effect was to cause the deposition of thin layers of iron compounds and silica. The thin but extensive layers imply deposition in quiet water. Chemical changes took place subsequently, and the resulting thin banded ferruginous jaspers and magnetic cherts are characteristic of the series in Cape Colony; the correlated Pretoria series in the Transvaal is mainly an arenaceous formation, but only a small part of the Griqua Town series in Cape Colony is of that nature. In the Griqua Town series two other events of great importance are recorded; first the prevalence of glacial conditions, evidence of which has been found in many places between the Mashowing in lat. 26° and the neighbourhood of the Orange River in lat. 29½°; the second event was the recurrence of volcanic activity in Bechuanaland, Griqualand West, Prieska and the Transvaal. The lavas are andesitic in character and differ much from those of the Pniel and Zoetlief series. The lavas of the Ongeluk group are followed, apparently conformably, by strata of very much the same kind as those below the glacial beds, though some beds in the upper part of the series are green slaty rocks unlike any found below. The source of the sediments in the Griqua Town series, including the glaciated boulders, is unknown.

At the top of the Transvaal system in Cape Colony there is a marked unconformity; the rocks of that system must have formed dry land for a considerable period after their deposition, for they were in places partly or entirely removed when the next group of rocks, the Matsap series, was laid down. It is likely that the region of the Maremane anticline in Hay and Kuruman was to a large extent in its present condition at the commencement of the Matsap period, for the peculiar Blink Klip breccia, which is confined to that region, is older than the Matsap beds, and nearly or quite the whole of the Griqua Town series had been removed by denudation along the Gamagara ridge before the basal Matsap conglomerates were formed. There is a great divergence in trend between the folds south of the Orange River in Prieska, which affect the Transvaal system (north-west), and those which also affect the Matsap series (north-east), but it is probable that the two sets of folds were produced at about the same time.[1]

The Matsap series consists chiefly of coarse sandstones and quartzites with remarkably well-rounded grains. Though isolated pebbles are found throughout the greater part of the formation, beds of conglomerate are of exceptional occurrence; they are only known from the base of the series. Some of the pebbles in these conglomerates are of local origin.

[1] See *G. C.*, xiii.

This series is one of the several eminently arenaceous formations that seem to be characteristic of Africa generally and Southern Africa in particular; an important feature is that they contain few or no fossils. The Matsap series can scarcely have been formed in the sea, and its well-bedded character is against its being regarded as a purely subærial formation. It is probably an example of that great class of deposits known as "continental," formed either in a region without an outlet to the ocean or on sinking ground by rivers laden with sediment; the differences between such rocks and marine deposits is due to the absence of marine conditions, which precludes the formation of marine limestone.

Though now only represented in the west of Hay, Gordonia, Bechuanaland, and the Protectorate, the Matsap beds probably had a very much wider distribution in Pre-Karroo times. They are probably represented in the Transvaal by the Waterberg beds, and the intervening country, now occupied chiefly by older rocks, may have been covered by them. After their deposition there was a period of earth-movements which produced the greatest effect along the eastern border of the Kalahari; from the Ezel Rand in Prieska at least as far north as Kuis on the Molopo these beds were closely folded, and to a less extent faulted, and formed a considerable range of mountains, of which the Korannaberg and Langebergen are remnants. This folding must have been brought about while the beds we see now were still under a deep cover of later deposits, but what this cover consisted of is unknown. The oldest rocks which now rest on the folded beds belong to the base of the Karroo system and are unaffected by the folds. That this immense gap in the northern succession is partly represented in the south of the Colony by the Cape system (Lower Devonian to Carboniferous) admits of little doubt, but one of the great problems in South African geology is to find how much more of the Palæozoic, and perhaps Pre-Palæozoic, strata are missing in the north.

At the commencement of the Cape period, *i.e.*, about Lower Devonian times, we may imagine that a great tract of land lay west and north of the position of the southern part of the Colony, for the materials comprising the Table Mountain series become somewhat coarser in those directions. That land furnished the enormous amount of sand, almost entirely of quartz grains, that now is the Table Mountain sandstone. This sandstone, which is roughly in the form of a broad belt about 500 miles long and 100 wide, was deposited in shallow water; denudation and earth-movements have played a greater part in defining its present boundaries than original deposition. During its formation the floor must have been gradually sinking to allow of the accumulation of 5,000 feet of sediment which throughout bears evidence of deposition in shallow water. The shale bands may possibly indicate deeper water conditions, but not necessarily so; the striated boulders in the Pakhuis shales and mudstone and in the sandstone of Table Mountain prove that glacial conditions prevailed for a time during that remote period. The fact that the series is thinner near Nieuwoudtville, at the extreme northern end of the area occupied by the overlying Bokkeveld beds, than farther south, points to the subsidence which allowed of the accumulation of the sandstones having gradually proceeded northwards. This means that deposition began in the south earlier than in the north, so that the bottom of the series in the Bokkeveld Mountain area was formed later than the lowest beds in the Worcester or Ceres Divisions.

We cannot regard the Table Mountain series as a marine formation; it is probably a fluviatile deposit laid down near the source of origin of the materials composing it. The great thickness of sediment, and the evidence throughout that it was laid down in shallow water, prove that the area occupied by it underwent slow but steady depression, which continued for a long period after the peculiar conditions under which it was formed came to an end. This depression in the southern part of the Colony must have gone on till some time during the deposition of the Karroo formation, perhaps till late in the Beaufort period; it was brought to a close by the earth-movements which produced the southern and western mountain ranges.

The northern limit of the depressed area cannot be defined, but it probably lay to the north of the thirtieth parallel; beyond the Orange River there was probably land.

During the Bokkeveld period the waters of a southern ocean that lay south and west of the Colony, and which spread at least as far as the position of the Falkland Islands and the South American Continent, gained access to the area where the Table Mountain series had been deposited. The presence of plant remains in the Bokkeveld beds, along with the marine shells, shows that the land on which the plants grew was not far off. In the account of the Bokkeveld beds in chapter iv., the generally noticed increase of sandstone towards the north and west was explained on the supposition that the sediments were chiefly derived from land lying north and west of the districts where the Bokkeveld beds occur.

Marine conditions prevailed in the southern part of Africa till the middle of the Bokkeveld period, when open connection with the sea seems to have been cut off, for in the muds, shales and sandstones of the Upper Bokkeveld and the Witteberg series only plant remains have been found. The cause and manner of this loss of connection with the ocean cannot be explained, as the evidence which might solve the problem lies below the waters of the Atlantic. The abundance of sandstones in the Witteberg beds, with their occasional white quartz pebbles, often in some respects closely resembling the Table Mountain sandstone, point to a recurrence of the conditions under which the latter was formed, though the frequence of thick shale bands proves that much of the finer grained sediment came to rest within the Colonial area in Witteberg times, while in the earlier period of the Table Mountain sandstone much less of the clays and silt, which must have been produced during the destruction of the rocks that furnished all the sand now forming the Table Mountain sandstone, remained in the same area.

Plants are the only fossils hitherto discovered in the

Witteberg beds, and they are usually found in fragments, bits of stems without leaves or other organs, and these fragments probably drifted far before becoming waterlogged. In the Eastern Province some beds are largely made up of compressed coaly-looking stems. Current bedding and ripple marks are very usual phenomena in the Witteberg series. In the south of the Colony the Witteberg period was brought to an end by the deposition of the green shales and mudstones of the Lower Dwyka beds, and no physical break or unconformity separates the two groups of rock. Deposition must have gone on continuously in the south of the Colony while the great change of climate took place that caused the glaciation of the country to the north of the Karroo.

While the deposition of sediments of various kinds went on uninterruptedly in the southern districts from the time of the Table Mountain series till far on in that of the Karroo formation, a rising of the floor began in the country north of the thirty-third parallel at some time during the Bokkeveld or Witteberg periods; for both in the west and east of the Colony north of that parallel of latitude an unconformity separates the lowest beds of the Dwyka series from the Cape formation. This rising of the land relatively to the water level must have taken place very gradually, as there is no strong discordance between the newer and older rocks. The Witteberg and Bokkeveld beds become gradually thinner and thinner northwards owing to the removal of a greater thickness of the beds in that direction during Pre-Dwyka times.

It is clear that in the country immediately north of Karroo Poort, where the only beds usually met with in the southern districts that are missing are the Lower Dwyka shales, the exposure of the Witteberg series must have been of very short duration. Farther north their exposure to the agencies of denudation began at an earlier time, so that more and more of the Witteberg and Bokkeveld rocks were washed away before the Dwyka conglomerate was laid down upon the remnants. It is obvious that deposition and denudation on a large scale cannot go on at the same time in one and the same district, so that at Matjes Fontein on the Oorlog's Kloof River, where only the lowest of the Bokkeveld beds remain between the Dwyka conglomerate and the Table Mountain sandstone, and where some 2,000 feet of the Bokkeveld beds, if the series was ever so complete there as farther south, are missing, the removal of the rest of the group must have taken place during the formation of the Witteberg beds in the south. We can be certain, therefore, that the Witteberg beds were never deposited in the area just north of Matjes Fontein (Oorlog's Kloof River).

The northward extending depression, which allowed first the Table Mountain sandstone and then the marine beds of the Bokkeveld series to be deposited north of the thirty-third parallel, gave way to the opposite movement of upheaval at some time during the deposition of the upper part of the Bokkeveld or lower part of the Witteberg group.

It is possible that this change of direction in the vertical movement of the land was coincident with the beginning of the change in geographical conditions which eventually brought about the cutting off of the Colonial area from the ocean in the middle of the Bokkeveld period.

The shore line at the commencement of the Dwyka period lay in an approximately east and west direction through the neighbourhood of Karroo Poort, and the shales and muds which were deposited near it are very like the more argillaceous sediments of the Witteberg series; they contain none of the fossil plants found in the latter, but a few plants of a similar nature to some of those found in the Ecca beds have been obtained from them. This shore line appears to have gradually crept northwards, but it did not gain much upon the land area to the north before the conditions set in that caused a general glaciation of that land.

There is clear evidence in Griqualand West, Hopetown, and Prieska that a long valley led south-south-westwards east of the escarpment of the Kaap in Dwyka times, and that it received tributaries from the country to the east and west; this valley was probably in existence during the deposition of part of the Cape system.

We have seen in a previous chapter that there can be no doubt of the fact that South Africa north of the thirty-third parallel was in part, at least, covered with snow and ice, and that the Dwyka tillite is made of the mud, sand, pebbles and boulders derived from the glaciated country.

In the northern parts of the Colony, as well as in the eastern districts of the Transvaal and western portion of the Orange River Colony, the Dwyka tillite has to a certain extent the character of a morainal deposit. It lies upon a well-striated rock surface, and is a hard sandy mud or clay with large blocks and smaller fragments of various kinds of rock scattered through it.

The boulder-beds, etc., of the Vaal-Harts Valley can be regarded as of fluvioglacial origin, while the occasional patches of tillite with a shaly matrix may have been formed in small glacial lakes within the morainal area, *i.e.*, the area which belonged to the land rather than to the water.

Evidence of the movement of solid ice over a surface of earlier deposited tillite occurs as far south as Eland's Vlei in the Western Karroo. In Natal, 2° north of that latitude, the tillite rests upon a glaciated surface of the Table Mountain series. It seems likely that the tillite to the south of Eland's Vlei also rests upon a glaciated surface of the Bokkeveld or Witteberg beds, but this has not yet been proved.

The Dwyka series in the south is certainly much thicker on the average than it is north of the Karroo, and a gradual diminution in thickness has been noticed in passing northwards along the western border of that country from Karroo Poort to Calvinia. This is in perfect concord with the fact that the transgression, or gradual extension of the water area, and consequently of the shore line, took a northerly direction as shown by the increasing gap in the succession below the Dwyka series. There are no representatives of the Lower Dwyka shales in the north, and a considerable thickness of the southern tillite must have been deposited before the northern tillite began to be laid down. The few feet of tillite at Kimberley, for instance, were probably formed during the deposition of the uppermost part of the southern tillite.

The tillite in the south of the Colony was probably formed entirely under water; into the sand and mud there being deposited the pebbles and boulders, many of them well scratched, were dropped by the floating ice that drifted southwards from the shore.

No remains of animals have been found in the tillite, so the question of the nature of the water in which it was deposited is unsettled. The absence of marine shells is certainly presumptive evidence against the water having been a part of the ocean, for it is well known that a cold climate is by no means unfavourable to marine life at the present day. Many genera of molluscs and crustaceans are represented by unusually large species in arctic and antarctic regions. In any case the absence of fossils is difficult to explain, but considering also that only land or fresh-water forms have been found in the beds underlying and overlying the tillite it is more probable that the water in the Dwyka basin was fresh than salt. The absence throughout the Karroo formation of deposits of rock salt, gypsum or other substances that accumulate in inland basins with no outlet is good evidence that the basin in which the rocks were formed was kept fresh by the continual escape of the water.

We may picture to ourselves a great inland water basin, with one or more outlets to the ocean towards the south, and covering what is now the southern part of the Cape Colony, at the commencement of the

Dwyka period. The southern mountain ranges were not yet in existence, the rocks which afterwards built them up were lying horizontally below the surface of the lake. The nearest land lay to the north; the southern portion of it consisted of the then recently exposed Witteberg deposits; north of this area there were belts composed of the Bokkeveld and Table Mountain series, while still farther north lay a hilly country composed of the Pre-Cape rocks. This country gradually became snow-clad, and glaciers and eventually a sheet of ice, of too great size to be called a glacier, slowly moved towards the lake, carrying with it mud, sand, pebbles and large blocks, derived from the surrounding land. Most of these materials reached the bottom of the great lake, but it is more than likely that parts of the unbedded tillite in Prieska and elsewhere in the northern districts are the remnants of moraines that lay between the ice and the floor in the lower parts of the land, or that were piled up in front of the ice. Meanwhile the floor of the lake sank, so that at least 1,000 feet of conglomerate accumulated over the southern part of the Colony; the water stretched farther and farther north as time went on, so that at the close of the glacial period shales were being deposited at least as far north as the Molopo.

The thousand feet of mud and stones which must extend over thousands of square miles under the southern part of the Karroo, and formerly spread as far south as Worcester, and very probably farther than the present southern limit of the continent, represent the products of denudation of a large tract of country during a long time. The wide distribution of the striated blocks and pebbles, which are found wherever the outcrops are sufficiently good to allow one to observe the contained boulders, shows that the glaciation was no merely local phenomenon, to be likened to the very limited snow and ice covered areas within tropical Africa at the present day, but that it was a widespread glaciation, extending over a large part of the continent north of the Karroo area. The source of the Dwyka boulders has been described in an earlier chapter, and we found that though the origin of many is at present unknown, yet a sufficient number have been recognised as having come from the Pre-Cape rocks north of the Karroo to show that the main source of the Dwyka series, so far as the Colonial area is concerned, lay to the north; the evidence hitherto noticed of the movement of the ice in the northern districts is to the same effect, *i.e.*, that the ice moved southwards from those districts. Whether land to the south also contributed ice-borne *débris* is unknown.

There is evidence from India, Australia, South America and the Falkland Islands that beds of glacial origin lie at the base of the rocks containing the Glossopteris flora, just as the Dwyka tillite does in South Africa; so the cold climate which gave rise to the glacial deposits affected a very large part of the earth's surface during more or less the same period, though it is not known that the cold climate was of equal duration in every part of that immense area. The explanation of the change of climate is not clear, though much has been written on the subject in recent years.

The theories can be grouped under three classes, astronomical, geographical and meteorological. The first seeks an explanation through change of position of the earth's axis of rotation or a decrease of the heat received from the sun; the former seems to be quite inadmissible, and the latter concerns a subject of which very little is known.[1] The geographical explanations are of two kinds, those which postulate the existence of extensive and high mountains, and those depending on the effect which would be produced by certain distributions of land and water; there is absolutely no support for the former hypothesis in South Africa, and the extensive area affected, together with the great probability that the country in Dwyka times stood not far above sea level, would seem to condemn it; the second class of geographical explanations is closely connected with the meteorological group, and though it is exceedingly difficult for others than physicists to estimate the value of the many hypotheses and calculations put forward, it seems that of all the explanations offered these alone are of any value. The chief condition to be accounted for is low temperature in moderate and low latitudes; this has been explained by supposing that there was less carbon dioxide in the air than now, for that gas hinders the loss of heat from the earth's surface by radiation into space; and by showing that the oceanic circulation might have been so arranged that warm water from equatorial regions did not greatly mitigate

[1] For a discussion of the possible variation of the amount of heat received from the sun see E. Dubois, *Arch. Mus. Leyden*, 1901, p. 311, and 1902, p. 73.

the polar temperatures. Profs. Chamberlin and Salisbury[1] have made a brilliant attempt to work out these hypotheses, and support them by geological evidence which is worth serious consideration. Their theory cannot be fully summarised here, but it depends chiefly on the effect of the formation of thick and extensive limestones in Carboniferous times in removing carbon dioxide from the air faster than it was renewed, a process which was continued in Permian times by the weathering of rocks on the supposed much greater land areas of that period; this extension of the land at the expense of the ocean is, in its turn, supposed to have brought about oceanic and atmospheric circulations conducive to cold climatic conditions in the areas known to have been covered with ice and snow.

There seems to have been in late Palæozoic times a great mass of land, whose boundaries are very imperfectly known, but which included part of Africa to the north of the Colony, a part of Australia, Eastern South America and a part of India, and which stretched across the Atlantic and Indian Oceans; on this land glacial conditions prevailed during a certain period. The flora and fauna of the land during and subsequent to the cold period were quite different to those which spread over the European and North American areas at the same

[1] *Geology*, vol. ii., pp. 655-77, London, 1906. For other discussions of this question see papers by T. W. E. David, and J. W. Gregory, *Congrès Géolog. Internat.*, 1906, Mexico. A. Penck, *Zeitschr. d. Gesellsch. f. Erdkunde zu Berlin*, xxxv., 1901, p. 239; E. Koken, *N. J. für Min.*, etc., Festband, 1907, p. 530. E. Philippi, *Centralblatt für Min.*, etc., 1908, p. 353. (An excellent general account of the Dwyka by this geologist is to be found in *Zeitsch. der Deutsch. Geol. Gesellsch.*, 1904, p. 304.)

time, for only a very few of the typical Karroo and Gondwana forms have been found in those regions. Some of the products of the denudation of this ancient continent—Gondwanaland[1]—accumulated in great fresh-water lakes, of which the Karroo area of South Africa is one. It is useless at the present time attempting to fill in the details of the history of the sediments derived from Gondwanaland; to discover, for instance, how many fresh-water basins existed, and to what extent they communicated with each other and with the ocean. In Cape Colony all the fossils yet found in these sediments lived upon land or were fresh-water forms, no distinctly marine animals are amongst them. In New South Wales, on the other hand, a striated boulder-bed has been found in strata containing marine fossils of Upper Carboniferous types. The discovery of marine fossils in German South-West Africa is proof, however, of an encroachment of the ocean upon the Karroo Lake in South Africa.

On the African portion of Gondwanaland at first grew *Glossopteris* and its associates mentioned on a previous page; and soon there appeared the remarkable reptiles, of which *Pareiasaurus* was one of the earlier and larger forms. *Pareiasaurus* and *Dicynodon* were certainly vegetable feeders, but carnivorous beasts were by no means wanting, a glance at the formidable teeth in such an animal as *Titanosuchus* is sufficient to convince any one that their possessors lived upon their fellows and did not graze on the *Glossopteris* and other plants that

[1] The name given to this hypothetical continent by E. Suess, *Das Antlitz der Erde*, vol. ii., p. 318, or p. 254 of the English Translation.

covered the ground. The bones now found in the Karroo belonged to bodies that were carried down by rivers or drifted from the shores of the lake.

The Karroo area, and with it probably the whole of the folded belt, must have sunk to allow the accumulation of the thousands of feet of sandstone and shale that we see in the Karroo formation. Occasionally perhaps wide stretches of mud or sand lay exposed for a time above the water, to be submerged again and buried under similar sediment. Such flat islands can now be recognised where the slight unconformities in the Ecca and Beaufort series mentioned in chapter v. are found.

The duration of this slow depression was unequal in different parts of the Colony; it was less along the southern and south-western area, where the Cape formation was thickest, than to the north. Probably while the upper part of the Beaufort series was being laid down, the folding began that eventually produced the great southern mountains. It is not yet known exactly when this process began, or when it reached its maximum, but there is little doubt that it was in progress during the later portion of the Karroo period. The numberless places along the southern edge of the Karroo where the Lower Karroo beds can be seen resting conformably upon and involved in the folds that affect the Witteberg, Bokkeveld and Table Mountain series, as well as the occurrence of the Dwyka and Ecca beds at Worcester, and the outliers on the northern edge and in the heart of the folded belt, prove conclusively that the main part of the disturbances took place after the Ecca beds were deposited. The Uitenhage beds, lying comparatively undisturbed upon the contorted strata belonging to the Cape formation, and in places upon the Pre-Cape rocks, give the clearest evidence for believing not only that the earth-movements responsible for the mountain chains had done their work before these beds were formed, but also that a tremendous amount of rock had been removed from the folded belt before that time. We have seen in earlier chapters that the Dwyka and Ecca beds belong to the later part of the Palæozoic era, to the period for convenience called Permo-Carboniferous, and that the Uitenhage beds are of early Cretaceous age. It was during the interval between those roughly defined periods that the mountain building in Cape Colony went on. In other countries this interval is represented by the Triassic and Jurassic systems, but in South Africa the only beds that can be referred to these are the Beaufort and Stormberg series.

The southern folding seems to have been produced by a thrust from the south towards the north, for the folds, where not symmetrical, tend to turn over towards the north. The minor ranges, such as the Caledon Mountain, Warm Water Berg and Touw's Berg are symmetrical, both limbs of the anticlines are equally inclined, and the same is the case with Anysberg, the western end of the Table Mountain sandstone ridge of the Zwartebergen; but in the high ranges, the main portion of the Zwartebergen and the Langebergen, the folds usually lean over northwards, so that both limbs of any one fold dip southwards. This structure seems to indicate that the region of the Great Karroo acted as a block against which the strata of the folded belt were crumpled and turned over. The over-thrust faults in the Dwyka series near Laingsburg also dip to the south, as though the pressure had to be relieved by the sliding of blocks of beds over the fractured edges of the next block to the north. It is on the south flanks of the most crumpled ranges that the great strike faults of Worcester and the Cango occur, and their downthrows are very considerable, reaching at least 10,000 feet at Worcester. The western folds are not nearly so intense as the southern, and may have begun at an earlier date. The easternmost of these anticlines, that which forms the Cederbergen, is also the greatest, and it is fairly symmetrical; no considerable folds lie parallel to it on the east; to the west, however, there are several parallel folds decreasing rapidly in amplitude towards the coast.

The neighbourhood of Worcester, where the Uitenhage conglomerates lie upon the Ecca beds and the Pre-Cape rocks on either side of the great fault, affords a grand object-lesson in denudation. To the north of the fault the conglomerates lie directly upon the Malmesbury beds; to the south, part of the Ecca, the Dwyka series and the whole of the Cape formation intervene between the two. The thickness of the intervening rock is not less than 10,000 feet. Between the fault and the mountains to the north of it over 10,000 feet of rock must have been removed during the interval (Jura-Trias) spoken of above. Nowhere else in the Colony is the evidence of this denudation so clear as at

Worcester, but with it before us we can believe that a similar amount of rock was removed from the Pre-Cape areas of Mossel Bay and the Cango, which are now partly overlain by the Uitenhage conglomerates. It must not be forgotten, however, that the Worcester conglomerates may be somewhat later in age than the similar rocks at Enon and Uitenhage, but the difference is certainly small.

When describing the dolerite intrusions of the Karroo we noticed that they seem to have avoided the folded belt; they occur to the north of it and on its extreme limits, where the intensity of folding is much less than in the major portion of the belt; we noticed also that this peculiarity in the distribution of the dolerite pointed to the folds having been in existence or in progress when the dolerite was intruded. Now the dolerite is probably of late Stormberg age, for the points of resemblance to the dolerites which are found in the volcanic beds are so numerous, and at the same time of more importance than the differences between them, that it seems that both the general mass of dolerites in the central and eastern parts of the Colony and the distinctly volcanic rocks belong to one series and reached their present position at about the same time, the end of the Stormberg period. The only other direct evidence of the age of the dolerites at present known is the occurrence of the rock as boulders in the Embotyi conglomerates, which we must regard as of Cretaceous age but probably younger than the Uitenhage beds. This fixes a later limit to the age of the intrusions. If the Embotyi beds should eventually prove to be of

Uitenhage age the limit will be correspondingly set back. But the first argument, concerning the connection of the dolerites and volcanic beds, certainly supports the assumption that the intrusions took place at the close of the Stormberg period, and this helps us to determine the date of the folding in the southern mountainous region.

Whether closer limits can be set to the period of folding than the Ecca and Uitenhage periods remains to be found out in the future. It is possible that the unconformity near Aberdeen, between the Ecca and Beaufort beds, described by the late Prof. A. H. Green, may be more than a local phenomenon, and if so it may lend material aid to the solution of the question, but so far as our knowledge of other parts of the Colony goes there is no physical break at that horizon. It may be that all traces of the unconformity which probably existed within the Karroo formation somewhere to the south of the main Colonial watershed have been removed by denudation. The uprising of the folded belt exposed the southern parts of the Colony to the air and to all the destructive agencies, such as change of temperature, wind, rain and streams, that this entailed. There were then formed the great longitudinal depressions between the Zwartebergen and Langebergen and the other more or less east and west ranges in the south. To this period probably belongs also the first rough shaping of the western coastal districts, the removal of the upper parts of the Cape formation from Malmesbury, Piquetberg and neighbouring districts, and the Olifant's River Valley (Clanwilliam). While this was going on the upper parts of the Karroo formation were being laid down in the north-east, possibly also far to the north and north-west of the existing boundary of the Stormberg series. The time represented by these rocks witnessed a great change in the inhabitants of the land round the Karroo lake. *Glossopteris* and many of its fellow-plants of the earlier period died out and were replaced by a new vegetation of which *Thinnfeldia*, *Tæniopteris*, *Baiera* and *Callipteridium* are the best-known members. The fauna likewise changed, *Dicynodon* and its congeners disappeared to make way for more highly organised reptiles.

Below the Molteno beds there is no direct evidence of a diminution in size of the water basin in which the Karroo formation was deposited, but the coarse sandstones in the Molteno beds and the overlying strata, the coal seams and the occasional thin conglomerates in the Molteno beds, all point to the proximity of land during their deposition.

The Molteno beds thicken southwards, and it is probable that the land at that time lay south and south-east of the area at no very great distance.[1]

The varying position of the base of the Drakensberg series proves that the Cave sandstone was subjected to denudation before the volcanic outbursts commenced, but there is also evidence in the interbedding of the two groups of rock that the denudation was local, and that the Cave sandstone continued to be formed after the earliest activity of the volcanoes. The outpouring of

[1] Schwarz, *T. P. S. S. A.*, xiv., 1903, p. 98. Du Toit, *T. P. S. S. A.*, xvi., 1904, p. 53.

the immense thickness of lava, described in a previous chapter, put a stop to the deposition of ordinary sediments, and the conditions under which sandstones, shales and other sediments are formed seem never to have prevailed again in the interior of the Colony. The present state of our knowledge of the volcanic series is too imperfect to allow a satisfactory statement of the effects due to the volcanic episode to be made; but it is certain that one result was to add a great volcanic pile to the north-eastern end of the newly emerged land.

The present main watershed of the Colony was probably produced during the Stormberg period by the rising of a low tract of country from the Karroo area, trending in a north-easterly direction. In trying to explain the fact that the southern rivers rise along the axis of a wide syncline and flow across its edge, one must remember that the deposition of the later part of the Karroo formation involved the levelling up of the basin and the disappearance of the synclinal structure in the uppermost beds. When, however, the land emerged, by up-warping, along what is now the watershed, the slope given to it caused the rivers to flow south-east and north-west, although the synclinal arrangement now exposed in rocks that were then deeply buried was not destroyed.

There seems no escape from the conclusion that denudation has proceeded uninterruptedly from the close of the Stormberg period (Jurassic) to the present day in the interior of the Colony. No deposits of later age, other than river gravels, alluvium and sand, have been found north of the folded belt.

During the Jurassic period the valleys in the folded belt were greatly enlarged and deepened, so that the Pre-Cape rocks became exposed in several areas south of the Zwartebergen, where the chief rivers appear to have had east and west courses. The rivers running south from the main Colonial watershed have left no trace of their passage through the mountain ranges in Pre-Uitenhage times. The water flowing southwards from the watershed probably drained away to the sea in an easterly direction. This denudation received a partial check in early Cretaceous times, so that the longitudinal valleys in the folded belt became filled with conglomerates, sandstones and shales, now represented by the outliers of Uitenhage beds described in chapter x. The cause of this may have been twofold, first, the sinking of the land, and, secondly, the coming in of a drier climate. That the former cause played an important part is evident from the fact that the marine Sunday's River beds occupy an old valley between Port Elizabeth and the Zuurbergen; and the second of the two causes is indicated by the nature of much of the conglomerates and sands, the Enon type of the Uitenhage beds. It is not improbable that the Uitenhage beds eventually covered the whole of the folded belt, with the exception of the higher parts of the mountain ranges; there is reason to believe that in places the lower passes in those ranges were buried under the gravels and other rocks of the Uitenhage series.[1] As we saw in chapter x., there is evidence to show that marine beds were formed as far west as Knysna.

[1] Rogers, *T. S. A. P. S.*, xiv., p. 375, 1903.

Towards the end of the Uitenhage period we may suppose that a low belt of land stretched north-east through the middle of the Colony, ending in a great mass of volcanic rocks, and that to the south of this land there were ridges of mountainous ground projecting above a shallow sea, or through gravel and sand deposited by local streams in a flat country only partially under water. Whether these sediments, in whatever way they were formed, spread north of the Zwartebergen will perhaps never be known, but it is possible that they did so, and that the streams flowing southwards from the main watershed eventually delivered their loads of silt into the same area instead of reaching the open sea to the south-east. It appears to be probable, however, that the rivers ran southwards across the newly deposited Uitenhage beds when the uplift occurred which put an end to the deposition of those beds in the folded belt.

These movements followed the strike of the rocks in the folded belt; their effect was to depress strips of the country between the mountain ranges and thus to accentuate the former longitudinal valleys, but though the Uitenhage beds were thus given various dips, usually in a northerly direction, they were not folded in the same manner as the Cape and Karroo formations.

The extent to which the dislocations were carried was, however, insufficient to disarrange the already established southward courses of the rivers draining the Karroo. These rivers gradually cut down their valleys through the Uitenhage beds, so that they reached the underlying sharply folded Cape formation, a process that still continues; but, as we shall see, there have been periods of diminished downward erosion during which the rivers widened their valleys and cut extensive plains instead of deepening their channels. The river systems south of the main watershed thus developed on a country whose structure has no direct relationship to the origin of the main rivers, and the deep gorges of the transverse streams, such as the Gamka and Gouritz, were cut by the action of the rivers in sawing their way downwards through soft and hard rocks alike as they were exposed. It is certain that the earth-movements of post-Uitenhage age deepened the depression between the Zwartebergen and Langebergen, but the movements were greater in some places than others, and were not sufficiently regular in direction and extent to deflect the chief transverse streams into valleys parallel to the mountain ranges.

In the marine beds of the Uitenhage series we have the inshore deposits of an ocean that stretched from India to South Africa, but its general form is very imperfectly known. So far as South Africa is concerned, that ocean probably only touched the country and never spread over what is now the interior of the Colony. The next inroad of the open sea is recorded in the Umzamba beds of the south-east coast. The fossils in these rocks are most closely related to Indian forms, and indicate that the beds were laid down at a later stage of the Cretaceous period than the Sunday's River beds. The fact that the Umzamba and the Embotyi beds are faulted down against the Table Mountain series shows that they once extended farther inland than their remnants are found to-day, but as they are distinctly in-shore deposits, as opposed to those formed under deep-sea conditions, they probably never stretched far inland beyond their outcrops in Pondoland. We have as yet no sign of a passage from the Uitenhage into the Umzamba series, but negative evidence on such a point is worthless under the circumstances; we cannot, therefore, say whether the ocean retreated and returned, or whether a conformable group of beds, from the Uitenhage to the Umzamba series, once existed in or near the south-east limit of the Colony.

The course of events north of the watershed in the country drained by the Orange River is difficult to decipher; the mountain building which produced the southern and western ranges did not affect the north of the Colony, and no equivalents of the Uitenhage beds are known to exist in that region.

The earliest recognisable stage in the erosion of the Drakensberg is represented by a peneplain in Barkly East standing at an altitude of 8,000 feet above sea level. This must have been cut by the head-waters of the Orange River, when the continent stood at a much lower level than now, and long before the southern escarpment of the Drakensberg had reached its present position. Upon elevation this plateau was dissected and a peneplain formed at the 6,000 foot level, the terrace being visible over the greater part of the Stormberg region.[1] It apparently extended north-westwards with a very gentle slope in that direction over the Orange River Colony into Griqualand West, where it is

[1] Du Toit, *T. S. A. P. S.*, vol. xvi., p. 53, 1905.

represented by the Kaap Plateau and the flat-topped chains of the Doornberg, Ezel Rand, Langberg, etc. The lower limit of its altitude here is 4,000 feet.

By a recurrence of the upward movement of the continent the Orange and Vaal Rivers have trenched deeply into this peneplain to a depth usually of 800 to 1,000 feet, in the Stormberg 1,500 feet. In the west the rivers have cut through the Karroo deposits which rest upon the Pre-Dwyka floor, and have laid bare the old drainage system which was in existence in that part of the Colony in Pre-Dwyka times.

The present drainage system has been greatly modified by its superposition upon that of Pre-Dwyka times, and the numerous terraces at various levels throughout the area prove the varying rates of downward erosion caused by barriers of harder rock. It seems very probable that the last uplift whereby the present features of the Karroo were determined was either of late or post-Cretaceous age.

The wide flats of the Karroo in the north of Cape Colony and in the Orange River Colony indicate a mature stage of erosion; the country having been cut nearly to a flat above which rise hills and ridges of more resistant rock generally produced by intrusions of dolerite. It seems not unlikely that for a certain period during this process of degradation of the continent arid or semi-arid conditions prevailed in the northern part of Cape Colony and in the Kalahari.[1]

Returning now to the southern rivers, which we de-

[1] Davis, *Geol. Soc. America*, xvii., p. 377, 1906. Du Toit, *Tr. Roy. Soc. S. Africa*, vol. i., pt. 2, 1909. Passarge, *Die Kalahari*, ch. xxxv.

scribed as cutting down their valleys through the Uitenhage beds to the underlying rocks, we must endeavour to trace the events which have taken place since they began to cut through the partially buried mountain ranges. Throughout the southern districts of the Colony there is abundant evidence bearing on this portion of its history; this evidence is given by the gravel and alluvial terraces lying high above the beds of the modern rivers.[1] The absence of contoured maps and a close knowledge of the height of the terraces greatly increase the difficulties of the problem, and it would be useless to attempt more than a sketch of the main conclusions to be derived from the facts at present known. The oldest, or highest, well-developed terraces lie over 1,000 feet above the modern river beds, and there are still more elevated terraces. When the rivers from the Karroo flowed at levels about 1,000 feet higher than at present their downward cutting powers were checked, and they, together with their tributaries, planed off the country to a more or less common level, producing a slightly undulating plain, from which rose the long mountain ranges and the smaller anticlines, such as the Caledon Mountain and Warm Water Berg. The distinct terraces forming conspicuous features on the slopes of the Langebergen and Zwartebergen, where the hard folded quartzites are cut to a nearly flat surface, were made during this period of lateral erosion. The cause was widespread, for we find its effects from the Transkei to

[1] See also Schwarz, *Q. J. G. S.*, lxii., 1906, p. 70; *Am. J. S.*, xxiv., Sept., 1907; *Geogr. Journ.*, March, 1907; *T. S. A. P. S.*, xv., 1904, p. 43.

the Zwart Ruggens west of the Karroo. An obvious possible reason for the cutting of these terraces is that the sea stood higher relatively to the land than is the case to-day, but whether the rivers had previously cut their channels down to sea level and so were unable to deepen further their valleys, or whether the country as a whole sank and therefore checked the deepening of the valleys, is not certain. The former is perhaps the more likely, for no filled-up channels far from the coast have been found, and they might be expected had the valleys been eroded to a greater depth than could be maintained under the new conditions. Local plains might well have been formed behind the larger blocks of mountains, just as we see wide alluvial flats in the course of the Buffel's River behind the Leeuw Kloof Poort and the plain cut by the Olifant's River before entering its gorge in the Gamka Hills. The terraces on the flanks of the mountains, with the outlying table-shaped fragments of the plains that formerly connected them, are so extensively developed, both to the north and south of the Zwartebergen, that they cannot be explained by a local cause like that which is sufficient to account for the alluvial flats of the Olifant's River. It is probable that the high-level plateau in the country south of the Langebergen was formed at the same time as the terraces we have been discussing, although it lies at a lower level, for then, as now, the rivers must have had a fall towards the coast, and each gorge through the great ranges was perhaps more steeply graded than the valley-bottom above or below it.

The rising of the country relatively to the sea level renewed the downward cutting powers of the rivers and restricted the stream erosion within narrow limits, so that great parts of the old plains were permanently abandoned. The change in the drainage system thus effected was considerable in certain areas; the watershed between the Olifant's and Baviaan's Kloof Rivers now lies on a high-level gravel plateau, and before the platform was cut the watershed may have been far from its present position.

At the present time the Dwyka and Gamka traverse the Zwartebergen together by the Gamka Poort, and at a point thirty miles below that gorge the Buffel's River joins them to form the Gouritz River; to do this the Buffel's River turns sharply to the east, away from what one would suppose its proper course to have been; the depression on the crest of the Langebergen, called Garcia's Pass, lies directly in the supposed normal course of the river, so it is not unlikely that its upper part was captured by a western tributary of the Gouritz. This must, however, have happened before the high-level plain was cut, for the summit of Garcia's Pass lies higher than the terrace on the north flank of the Langebergen.

There are other terraces at lower levels than those mentioned above, but to bring all these into order and to place them in chronological sequence is at present impossible on account of the lack of detailed information as to their relative heights and distribution.

The raised beaches and the limestone formed from sand dunes now lying at considerable heights above the shore and at some distance inland, must belong to one of the periods of plain-cutting; there is as yet insufficient evidence to correlate these phenomena definitely, but it may well be that the higher shore terraces, such as that covered by the marine gravels of the Zwartkops Heights, and the old beach underlying the limestone of Cape Infanta, were removed out of reach of the waves when the inland plateaux, 1,000 feet above the modern river beds, were elevated.

The numerous S-curves of the southern river valleys with precipitous sides, often several hundred feet high, are relics of the time when the streams meandered slowly across nearly flat plains; on the fall of the streams being increased by the rise of the land their downward cutting power was renewed and they deepened the valleys in which they flowed, so that in many cases the S-bends were retained and deepened to the extent we now see. One of the most remarkable of these is the S-shaped gorge in the Klein Zwartberg occupied by the Buffel's River; another has been cut by the Gamka between the Roode Berg and the Pogha Hills; from the Eastern Province the extremely sinuous and deep valleys of the Great Fish, Kei and Bashee Rivers are analogous examples.

Hitherto we have only given the evidence for elevation of the land relatively to the water in connection with the superficial deposits. There is, however, evidence of a contrary movement; the great depths of the estuarine shelly sands and muds near the mouths of some of the rivers, especially the Zwartkops and Buffalo Rivers, which are the only ones that have been explored in this sense, may be due to depression. On the west coast, Saldanha Bay, an almost land-locked basin in granite, appears to be a drowned valley. There is no well-defined valley entering the bay, though the thick superficial sandy deposits that stretch south-east of the bay may conceal an old river channel. At many places in Saldanha Bay the dune limestone containing the remains of land snails passes below sea level, as is also the case near Struys Point and the mouth of the Duiven Hoeks River on the south coast. At Paternoster, north of Saldanha Bay, a well sunk at a spot about twenty feet above sea level revealed the presence of ninety feet of sandy limestone and sand containing land shells, tortoise bones, and broken marine shells, evidently an accumulation formed on the land behind the beach, and not below tide level. These facts all point to a recent depression.

The origin of the coast line has given rise to controversy. From certain facts, that the west and south-east coasts are remarkably straight, and that there is a broad coincidence between the trend of the southern coast generally and the strike of the rocks in the mountain belt, it has been supposed[1] that the coast as a whole had been defined by faults, an hypothesis that was supported by a misunderstanding of the structure of the country between the Drakensberg and the Indian Ocean. No faults which run parallel to the coast and drop the rocks on the ocean side have been found in the west coast country within the Colony, and south of the folded belt the coast cuts slantingwise across the folds and

[1] E. Suess, *Das Antlitz der Erde*, vol. i., chap. vi.; S. Passarge, *Die Kalahari*, pp. 595-96; and Petermann's *Geog. Mitteil.*, 1908, Heft vi.

faults alike; it is only along the few miles occupied by the Umzamba series that a fault probably runs parallel with the coast; the fault which separates the Embotyi series from the Table Mountain series at Waterfall Bluff passes inland westwards between the Karroo beds and the Table Mountain series of the Egossa Forest, giving rise to a marked escarpment, while the Embotyi series rests nearly flat on the inclined Karroo beds. An important fact in connection with this question of the origin of the coast is that along any line of section from the Karroo to the coast the younger rocks lie inland and the oldest crop out along the coast. The only exception to this generalisation is the occurrence of the various Cretaceous series, filling old valleys or forming a mere fringe. Had faults played an important part in the shaping of the coast we should expect to find strips of the Stormberg beds in the territories, or of the lower members of the Karroo system in the west coast belt, due to faulting since the crumpling of the folded belt, but such structures have not been found. The Karroo outlier in Worcester and Robertson is certainly due to the process of mountain folding, and the country south-west of it presents bold escarpments of the Table Mountain series to the ocean, or the latter is bounded by low-lying or hilly ground made of more ancient rocks fronting such escarpments.

Recently Prof. Penck[1] published a general account of the coast line in relation to the structure of South Africa and arrived at the conclusion that the land is a

[1] *Der Drakensberg und der Quathlambabruch*, *Sitzungsb. d. Königl. Preuss. Akad. d. Wissenschaften*, xi., 1908, p. 230.

bent surface of denudation, and that the position of the coast roughly marks the axis about which the bending has taken place. He shows how the variation in level of the axis, lying either just above or below that of the sea, would account for the presence of such apparently contradictory phenomena as drowned valleys and raised beaches in one and the same district. This suggestion certainly throws light on many of the coastal phenomena from the Olifant's River round the south coast to the Natal border, of which the geology is known in at least its outlines. For a thorough discussion of the suggestion as regards the Cape Colony coast, more information is required about the thickness of the sediments lying on the bed rock of the river channels in their lower courses, and about the slopes of, and deposits on, the coastal terraces.

CHAPTER XIV.

ECONOMIC GEOLOGY.

ALTHOUGH but little has been written concerning the mineral resources of the Cape Colony, the subject is one that can only be briefly and inadequately touched upon here.

Asbestos.—White asbestos (chrysotile) has not yet been found in any quantity. Blue asbestos (crocidolite) is being mined with success at various places in Prieska and Hay. The mineral is found in layers interbedded with the hard banded jaspers and ironstones of the Griqua Town series, the fibres being more or less perpendicular to the bedding planes. The fibre varies in length up to three inches, but it is usually much below that length. The mining is very simple. In many places the asbestos has suffered oxidation and silicification, and has been changed to the hard brown mineral commonly, but wrongly, known as crocidolite.[1] The amount available must be immense, for the mineral has been observed in the Lower Griqua Town beds at numerous localities from the Orange River northwards to the border of the Bechuanaland Protectorate.

[1] For an account of the mode of occurrence, etc., see *G. C.*, x., pp. 158-161.

Building Stone.—Considering the great development of sandstones in it the Cape Colony is apparently badly off for building stone. The chief reason probably is that but few quarries have been opened, so that the rocks in an unweathered state are not well known.

The Table Mountain sandstone furnishes a good rough building stone in many places, especially where it has not been disturbed by earth-movements, and the rock is therefore free from planes of shear. Owing to the quantity of unsuitable material that has often to be removed in quarrying it is not used so much as one might expect from the wide distribution of the formation. Rock from Table Mountain and the mountains to the south is largely used for foundations in the Peninsula, and to a smaller extent for buildings (*e.g.*, Huguenot Memorial Buildings in Cape Town); the Harbour Board Offices in Cape Town were built of stone from Grabouw just beyond Sir Lowry's Pass.

Good freestone is obtained from the Dwyka series close to Modder River Station, and from the Beaufort beds near Beaufort West, Fort Beaufort, Graaff Reinet, Kingwilliamstown, and Queenstown (University Offices in Cape Town and the new laboratories at the South African College), and there seems to be no reason why as good stone should not be obtained at various points along the Midland Railway system as well, such as at Naauwpoort, Steynsburg, etc.

The Molteno sandstones are usually very coarse in texture though easily worked, but a good freestone is represented in the Cave sandstone, a formation which is unfortunately only accessible at Lady Grey (Aliwal North).

The Uitenhage series furnishes good freestone at Oudtshoorn.

The dolomitic limestone of the Campbell Rand series makes an excellent building material, as it occurs in very uniform layers and is easily worked; both it and the Black Reef beds are much used locally in the north.

The granite of the Peninsula is much used for foundations and for coping, but is often disfigured by dark patches. A fine example of this stone is to be seen in the Rhodes Memorial above Groot Schuur. The granite of the Paarl and Kraaifontein is finer grained and not so coarsely porphyritic.

The dolerite of the Karroo is very durable, but it is hard to work, while its dark colour is unpleasing to the eye. It is an excellent stone for road metal, and much preferable to the granite or impure quartzite generally used in the Peninsula.

At Hoetjes Bay, an inlet of Saldanha Bay, a recent limestone has been extensively quarried. A piece of this limestone contained a smaller proportion of quartz sand than usual in such rocks, about 12 per cent., but the composition may vary considerably. When newly quarried it is soft and can be easily worked, but it hardens on exposure. From the appearance of the surface in such buildings as the General Post Office and the South African Museum in Cape Town, the Saldanha Bay stone does not appear to be a durable one in the Cape climate.

Clays.—Clays suited for the manufacture of tiles or pottery-ware are rather poorly represented in the Colony. In a few localities in the Western Province slates of the Malmesbury series furnish, when decomposed, a clay that can be utilised for such a purpose, while red clays belonging to the Uitenhage formation are worked near Rawson Bridge, Despatch and Uitenhage. The blue-grey clays of the Uitenhage series at Heidelberg are made into good tiles, pipes, and bricks. Thick deposits of clay have been found in a few localities underlying the sand and gravel of the Cape flats; they include china clays of excellent quality. Beds of fire-clay are associated with some of the coal seams of the Molteno beds, and at Cyfergat a seam is being mined for the manufacture of bricks. Thick beds of fire-clay have been proved overlying a seam of coal just north of Sterkstroom and underlying the coal of the Guba Valley, near Indwe.

Coal.—As already stated in describing the "White Band" of the Dwyka series, much prospecting for coal has been done in this zone of carbonaceous shale without any encouraging results, neither has any evidence yet come to light in support of Dunn's view as to the probable existence of workable coal a little above the Dwyka conglomerate under the Karroo.

The lowest geological horizon at which coal has been found belongs to the Lower Beaufort beds, for behind the Komsberg escarpment there is a seam about nine inches thick on the farm Lange Kuil, while thicker seams have lately been discovered in the escarpment a little distance to the south-east. High up in the Nieuweveld escarpment at Leeuw River Poort, and also in the Camdeboo, there are some remarkable vertical cracks filled with bright bituminous coal.[1] The fissure at Leeuw River Poort has been proved to be over 300 feet in depth and varies in width from twelve feet downwards. It does not maintain a straight course, but at places runs at a low angle or becomes horizontal. It passes through a few horizontal layers of coal, under an inch thick, in a band of sandstone. The coal in the fissure is remarkably free from ash, an analysis giving only 0·8 per cent. The fissure seems to have been produced during the intrusion of the dolerite sheets which occur in the Nieuweveld, and the bituminous coal was probably partly squeezed and partly distilled into it at the same time.

The coal at Buffel's Kloof, Camdeboo, occurs in a similar manner, and no seam worth working has been met with there. The other reports of coal in the Western Karroo are generally based upon the occurrence of carbonised wood in fragments.

A thin layer of coal was proved by a well in the Middle Beaufort beds at Ludlow Siding a little north of Rosmead Junction, but the seam is not worth working.

In the Molteno beds there are numerous outcrops of coal, but the workable seams are restricted to three well-defined horizons. The lowest one is that of the *Indwe seam;* to this belong the coals at Indwe, Cala and that near Engcobo, but the seam is only being worked at the first locality. The second horizon is about eighty feet higher and is known as the *Guba seam.* It is present in the Guba Valley near Indwe, at Bushman's

[1] E. J. Dunn, *Report on Camdeboo and Nieuweveld Coal,* Cape Town, 1879; Schwarz, *G. C.*, ii., p. 24; and for a similar occurrence in East Griqualand, *G. C.*, vii., p. 16.

Hoek, and at Sterkstroom. The uppermost is the horizon of the *Molteno seam*, 300 feet above the Indwe seam; to it may be referred the coals at Molteno and Cyfergat, Bamboes Spruit, and the thin seams at the Cala Pass, Olyve Fontein a little to the south-west of Aliwal North, and Gubenxa in Elliot.

The layers of coal seldom exceed twelve inches in thickness (in the Guba seam there is one about twenty-five inches thick), but as several usually occur alternating with thin bands of black shale it is possible to extract from three to four feet of coal in mining operations. The working costs are enormously increased by the presence of these thin shaly layers.

On all three horizons these composite seams appear to occupy a number of detached areas, in between which the coal is either replaced by shale or else is entirely absent. In most cases this is due to non-deposition of carbonaceous material, but sometimes to erosion of the matter deposited—contemporaneous erosion, a phenomenon which is seen in thousands of cases throughout the Karroo beds. At Indwe the upper layers of coal and shale are in places missing, and the surface thus denuded is overlain by massive sandstone with pebbles at its base.

The coals of the Molteno beds[1] are usually laminated and contain very thin streaks of shale; they are coals

[1] For fuller details see the following:—

E. J. Dunn, *Report on the Stormberg Coal Fields*, Cape Town, 1878; F. W. North, *Report on the Coal Fields of the Stormbergen*, Cape Town, 1878; A. H. Green, *Report on the Coal Fields of the Cape Colony*, Cape Town, 1883; W. Galloway, *Report on the Coal Deposits in the Indwe Basin and Stormberg Range of Mountains*, Cape Town, 1889; and *G. C.*, viii., ix. and x.

which were formed very probably at a considerable distance from the spot where the plants grew, and the alternation of thin layers of coal and silt evidently points to the vegetable matter having been deposited over the floor of the basin in the same manner as the silt. It is this silt which accounts for the high percentage of ash in the Stormberg coals.

The abundant intrusions of dolerite in the form of dykes and sheets, especially the latter, have had an injurious effect upon the coal. The distance through which this influence has made itself felt varies; the chief effect is the driving off of the more volatile constituents with the development of an anthracitic character culminating in the coking of the coal, which is thus rendered unsaleable. The insertion of a few analyses of the coals taken from the official reports just referred to may be of use in indicating the class of coal to which the Colonial seams belong:—

	Molteno.	Cyfergat.	Indwe.	Bamboes Mountains	Matatiele.	Cala.
Moisture	1·13	2·24	17·34	1·45	1·37	1·50
Volatile Hydrocarbons	10·31	21·25	...	19·16	24·68	9·50
Fixed Carbon	60·89	51·04	61·80	54·92	47·53	68·51
Ash	28·80	23·86	21·53	23·90	25·10	19·70
Sulphur	0·76	1·48	...	0·93	1·33	0·79
Total	101·89	99·87	100·67	100·36	100·01	100·00

While the amount of ash is considerable, much higher than in most of the other South African coals, it must be noticed that the percentage of sulphur present is very low indeed.

From the results of numerous tests on the railways it has been found that the average weight of water evaporated at and from 212° F. in an engine boiler per pound of coal burnt is 5·0 in the case of Stormberg coal, and 5·5 in the case of Indwe coal, as compared with 7·5 in the case of Welsh coal.

The annual output from the Indwe and Stormberg collieries has been usually close upon 200,000 tons, the former contributing a little more than 60 per cent.

A material allied to torbanite (oil shale) occurs below a coal seam in Matatiele.[1]

Copper.—All the copper ore raised in the Colony comes from Namaqualand, the important mines being the O'Okiep, Spectakel, Nababeep, Tweefontein and O'Okiep East, all in the neighbourhood of O'Okiep; most of these have been worked for some considerable period.

The ore is principally bornite with a lesser amount of copper-pyrites, and occurs in dykes of an igneous rock varying in composition from norite to hypersthenite and cutting across the gneiss in a nearly east and west direction.[2] The bornite is either disseminated through the dyke material or is collected together to form great masses, "pockets" as they are termed. The most remarkable feature is that the bornite appears to be one of the constituents of the hypersthene-rock, and

[1] *G. C.*, vii., p. 21.
[2] J. H. Ronaldson, *T. G. S. S. A.*, viii., p. 158.

the ore pockets have apparently been formed by concentration of the metallic sulphides in certain parts of the intrusions. This view was put forward by Wyley[1] as long ago as 1856 and has been confirmed by Schenck and other observers subsequently. The dykes are either poor or barren along considerable portions of their lengths, and Kuntz[2] has noticed that the ore-pockets are frequently located just where the formations are crossed by west-north-westerly breaks, or where the adjoining gneiss contains layers rich in iron.

There are many smaller mines in this neighbourhood which are being worked on a very small scale, while abandoned workings are numerous in the area known as the Richtersveld enclosed by the big bend of the Orange River in the extreme north of the district.

At Areachap, a little west of Upington, a copper lode has recently been opened out, the enclosing formation being the Kheis quartz-schists. Quartz veins carrying copper are present in various parts of Hay, Gordonia and Prieska in the same and in younger formations.

In the Mount Ayliff district in East Griqualand copper-pyrites and pyrrhotine have been found along the junction of the Karroo sediments with the great mass of intrusive dolerite forming the Insizwa Mountain. The ore is reported to be confined to the lowermost part of the dolerite, and may possibly be, as in the Namaqualand occurrences, a constituent of the igneous

[1] A. Wyley, *Report upon the Mineral and Geological Structure of South Namaqualand*, etc., Parliamentary Report, G. 36, Cape Town, 1857, p. 30.

[2] J. Kuntz, *T. S. S. S. A.*, vii., p. 70.

rock, especially as the intrusion is stated to contain a rhombic pyroxene and therefore to be allied to the norites. The occurrence is of interest in that the ore contains a fair proportion of nickel, as well as a certain amount of platinum.

At Bekker's Kloof near Cradock there is a vein in dolerite which carries several pennyweights of gold per ton in association with silver and copper.

Diamonds.—The diamondiferous deposits can be divided into two totally distinct classes according as the gem occurs (*a*) in pipes and fissures filled with blue-ground (kimberlite), or (*b*) in river-formed gravels.

(*a*) The former have already been discussed in chapter xi., and to that account there is very little more to add. It has been pointed out that in only an extremely limited proportion of pipes is the diamond present in sufficient quantity to repay the cost of working. It must be emphasised that whereas the minerals garnet and ilmenite, popularly known as "ruby" and "carbon," and mica are essential constituents of the blue-ground everywhere, though in varying proportion, there is strong reason to believe that such is not the case with the diamond, and that the occasional presence of the latter must be considered accidental. There are certain pipes, too, in which the diamond is sparingly present, but the kimberlite may be a "hardibank" and refuse to disintegrate when exposed to the action of the weather. Speaking roughly, this is more commonly the case in the smaller mines. The kimberlite fissures are still less promising in these respects, and only rarely contain diamonds. From another point of view, however, the kimberlite dykes are of value; wells or bore-holes sunk on them rarely fail to obtain supplies of water satisfactory both as to the quantity and quality, and this is especially valuable since they are numerous in an area that has a poor water supply, and one in which dolerite dykes are neither abundant nor satisfactory as water carriers.

(*b*) The workable diamondiferous gravels are confined to the valley of the Vaal River from Christiana down to its junction with the Orange. Similar gravels exist along the Orange at various points below Hopetown, but they have in nearly every case been converted, through the deposition of carbonate of lime, into compact conglomerates. The same is the case to a considerable degree with a patch of gravels on the Kaap Plateau at Mahura Muthla between Vryburg and Kuruman,[1] in which the diamond has been found. The Vaal River gravels[2] are found at various levels, occasionally as much as 400 feet above the bed of the present river, and often at a distance from it of several miles.

The principal "diggings" are at Klipdam and Windsorton and between Barkly West and Delport's Hope. In spite of the erratic yields and the smaller size of the stones there is a fair output annually, the "river stones," as they are called, being on the whole of a better quality and commanding a much higher price than those from the pipes. Much of the deposits has been worked over more than once, but there still remain untouched

[1] *G. C.*, xi., pp. 76-77. [2] *Ibid.*, p. 171.

patches with a heavy over-burden, or handicapped by absence of water-supply, which are likely to be treated in the future.

The source of the diamonds in these alluvial deposits has given rise to some controversy, inasmuch as the gems differ to a certain degree from those obtained in the pipes hitherto worked, and for this reason they have even been considered as derived from the Pniel amygdaloidal diabase of the Vaal River Valley,[1] though this view seems rather improbable.

Diatomite or diatom-earth has been found in certain pans in Bechuanaland and Griqualand West, *e.g.*, Witkop in Gordonia, and the pan on Craigie Burn near Belmont (Herbert). This material is probably not uncommon, but, in the midst of white calcareous tufa which always accompanies it, its presence is usually overlooked.

Gold.—Auriferous veins have been found in the Kraaipan formation[2] in Mafeking, at Madibi and at Kraaipan. At the former locality the reef which is being worked occurs in chlorite- and calcareous-schist and contains quartz, chlorite, calcite, pyrrhotine and pyrites. Generally speaking, quartz veins in the granite and in the massive banded ironstone have proved to be barren. Some of the cherts and granulitised quartz veins carry several pennyweights of gold in various localities. In Knysna[3] the Millwood goldfields lie among the Outeniqua Mountains, which are made of

[1] H. Merensky, *T. G. S. S. A.*, x., p. 107. [2] *G. C.*, x., p. 230.
[3] E. H. L. Schwarz, *G. C.*, x., p. 86; and *G. M.*, p. 369, 1905.

steeply folded Table Mountain sandstones. The strata are traversed by auriferous quartz veins carrying pyrites, galena, blende, and sometimes siderite. The gold obtained is all alluvial and is only found in very limited quantities.

In the Prince Albert Division on Spreeuw Fontein and the neighbouring farms gold in the form of dust and nuggets has been obtained for many years past, and from 1891-98 part of the area was proclaimed a public gold-field. The rocks which belong to the lowest Beaufort beds are gently folded and are traversed by quartz veins. The gold is found in loose pieces of quartz on the surface, but directly the reefs are sunk upon all traces of the precious metal disappear. The limonite pseudomorphs after pyrites in the sedimentary rocks often contain specks of gold. The gravels were rich in some places, and crystals of gold were even found in the hollow parts of fossil reptilian bones. Prof. Schwarz[1] considers that the source of the gold was in the Zwartbergen to the south, and that the metal was subsequently deposited in the gravels on a peneplain, the relics of which are seen in the flat-topped gravel-capped hills in the neighbourhood. Through the action of solutions, probably ferric sulphate derived from pyrites in the rocks, the gold was dissolved and the nuggets and crystals were formed in the spaces between the gravels and in cracks in the underlying strata. The contrast between the enormously rich fragments of vein quartz occasionally picked up on the surface and the barren vein quartz below the surface is very remarkable, but

[1] *T. S. A. Phil. S.*, xv., p. 54, 1904; and *G. M.*, p. 377, 1905.

that all the gold came from the mountains is improbable, for the metal undoubtedly exists in pyrites enclosed in the Beaufort sandstone.

Iron.—The iron ores of Cape Colony form almost inexhaustible deposits, but, owing to their geographical situation, are not likely to be worked for many years to come.

The formation is that facies of the Lower Griqua Town beds known as the Blink Klip breccia described on page 91 and forming two prominent belts striking northwards from near Postmasburg in Hay into the Kuruman Division. As already stated, it has been formed by the solution of the limestone underlying the banded ironstones, the fracturing of the latter, and the replacement of silica by hæmatite due to circulating waters. The formation varies from banded ferruginous rocks up to masses of pure hæmatite, and the amount of ore in existence must be enormous. Sedimentary rocks with large percentages of iron occur in the Marydale beds, Kraaipan beds, and the Lower Griqua Town beds from Prieska up to Bechuanaland; it is unknown at present whether the iron oxides are ever locally concentrated in these beds in other places than those occupied by the Blink Klip breccia.

Lead and Silver.—Galena, sometimes rich in silver, is known to occur in veins in the Campbell Rand limestone at several localities on the Kaap Plateau and also in the Griqua Town jaspers near Witwater, Hay. Argentiferous galena was found many years ago at the Maitland mines a little to the west of Port Elizabeth.

Limestone.—It will be sufficient merely to enumerate the principal occurrences of limestone, referring the reader to the account of the formation in which each is found.

In the Campbell Rand series blue-grey crystalline limestone, usually somewhat dolomitic in character, covers an area of thousands of square miles in northern Cape Colony and constituting the Kaap Plateau. Similar limestone occurs in the Cango area in Oudtshoorn; in the main outcrop are situated the celebrated Cango Caves.

In Van Rhyn's Dorp the Aties (Malmesbury) limestones make numerous outcrops along the Troe-Troe and Olifant's Rivers. White crystalline limestone (marble) is known to occur in Namaqualand. The Malmesbury series is generally deficient in calcareous matter in the south-west of the Colony, but, as already mentioned, crystalline limestone crops out in several localities between Porterville and Hermon, at Robertson, and near Port Elizabeth.

The lower portion of the Karroo formation contains a good deal of calcareous matter usually forming nodules and concretions, and but seldom collected together to form beds of any thickness or continuous for any distance. Much of the limestone is argillaceous and when burnt yields a fairly good hydraulic cement. Such limestones are frequently burnt for local use and are commonly known as "cement-stone".

Upper Cretaceous limestone is worked at Need's Camp on the Buffalo River above East London.

Porous limestones of recent age are well developed both in the interior and along certain portions of the coastal belt (see pp. 398 and 401), but in spite of their wide distribution the deposits are only worked in a few localities. The limestone obtained near Great Fish River Siding in Cradock is well known and is a good example of the tufaceous deposit occurring in the Karroo. The coastal limestones usually contain rather large amounts of sand and are often situated in inconvenient positions.

Lignite.—This substance, which for practical purposes may be considered as an inferior kind of coal, is found in the Uitenhage series and in more recent formations in the Cape Flats and the Knysna district. The presence of lignite in the Uitenhage series has given rise to much prospecting in the Uitenhage, Oudtshoorn, and Mossel Bay Divisions, but the quantity found has in each case been too small. Near Knysna, where lignite occurs in larger quantity than elsewhere in the Colony, an attempt is being made to manufacture briquettes, but the results are not yet known. Lignite has been found at many places under the sand of the Cape Flats, but at present there is no use for it.

Manganese.—Ores of manganese are found at a number of localities in the Western Province and are almost entirely confined to the Table Mountain sandstone. The deposits are found along lines of crush or fracture in the sandstone, and it seems very probable that small quantities of manganese ores are disseminated through the rock and that the mineral has been leached out by percolating water and collected in cracks and fissures or brought to the surface.

Veins of pyrolusite (manganese dioxide) have been opened out on Constantia Neck, at Du Toit's Kloof near the Paarl, at French Hoek and at Kogel Bay, while a peculiar deposit is found at the Caledon Baths which owes its origin to hot springs. The veins have so far proved disappointing, the limited amount of ore preventing their being worked on a large scale, otherwise the ores appear to be of sufficiently high grade to justify exploitation. The ore bodies tend to pinch out, and much that at first sight appears to be solid ore proves only to be a coating on the sandstone, and hence often the ore is very low in grade. Judging from the history of manganese mining in the Cape Colony a word of warning is sadly needed.

The following two analyses of ores were made at the Imperial Institute, London, the first sample having been obtained from Constantia Neck, the second from Du Toit's Kloof, Paarl :—

Manganese dioxide . .	83·93	77·13
Manganous oxide . .	5·55	4·04
Ferric oxide . . .	2·13	2·23
Silica	1·14	4·96
Phosphoric oxide . .	0·61	0·75
Sulphur	nil	nil

Mica.—White mica (muscovite) has been found in pegmatite veins in granite in various parts of Cape Colony, for example, Alicedale and Middel Water in Prieska. It is only rarely the case that sheets can be obtained exceeding a few inches in size, and almost invariably the flakes are bent or crumpled. The granites have been considerably affected by earth-movements subsequent to the formation of the pegmatite veins and the mica crystals have in consequence been distorted.

Molybdenum.—Molybdenite, molybdic sulphide, has been found in the granite near Helderberg (Stellenbosch) in quartz veins associated with mispickel, pyrites and chalcopyrite; also in Namaqualand.

Nickel.—Nickel has been found in the Mount Ayliff District in Griqualand East in association with copper (*q.v.*).

Petroleum.—Indications of mineral oil are not uncommon in the northern portion of the Karroo; the most important feature about their mode of occurrence is that the oily material is invariably found in association with, and even in cavities or vesicles in, dolerite intrusions; the same appears to be also the case in the Orange River Colony. This at once suggests that the oil is a secondary product due to distillation by the dolerite, at the time of its intrusion, of coal or carbonaceous shale below the surface. In Northern Cape Colony such a source for the hydrocarbons is found in the "White Band" of the Dwyka series, for, as has been stated on page 188, this horizon consists of very impure oil shales, the amount of carbonaceous matter in some cases rising to 12 per cent.; moreover, dolerite has very commonly been injected along these shales.

Some interesting occurrences of a similar nature have been found in the Stormberg area. For example, at Dordrecht a dolerite dyke cutting through a seam of impure coal contains minute vesicles filled with mineral oil. Again, in Barkly East oil and tarry matter are found in joints in basalt at Bulhoek (Smiling Vale), while at Moshesh's Ford small quantities of pitch occur in crevices in the agglomerate filling a large volcanic neck. The Molteno beds, containing occasional seams of coal, underlie all this area, and the existence of these small quantities of hydrocarbons is thus capable of explanation.

Salt.—In Cape Colony all the salt produced commercially is obtained from salt-pans. Such pans are numerous in the north, but it is surprising that the production of salt has been confined to so few of them, for the product has a considerable commercial value and the supply is practically unlimited. The salt-pans form one of the most valuable assets of the Colony.

As mentioned on page 412, most of these pans are located upon the Dwyka tillite or shales — namely, Riverton, Klokfontein, and the Salt-pan (Herbert), Zoutpan and Maritz Dam (Prieska), Zout Aar (Britstown), the Salt-pan, Rautenbach's Pan, possibly Matsiman Pan (Gordonia), and Commissioner's Salt-pan (Calvinia), to mention a few of the important ones.

Over the whole of Cape Colony water from the Dwyka formation is frequently of a very brackish character, and the source of the salt in the pans is therefore obvious, the saline material having been gradually leached out of the surrounding rocks and concentrated in the depressions constituting the pans.

A few salt-pans are situated upon the older formations—namely, Groot and Klein Chwaing in Vryburg, and Matsap in Hay.

In Central Cape Colony the only salt-pan of note is that at Maraisburg, on Beaufort beds. In the very important Zwartkops Pan, near Port Elizabeth, the salt has probably been derived from the clays of the Uitenhage series.

Along the coast salt is found in several localities where an arm of the sea has been shut off by a sand dune—namely, at Port Nolloth, Yzerfontein Point (Malmesbury), and Papen Dorp (Piquetberg), the last named being among the sand dunes.

Gypsum is found below the clay forming the floor of the Port Nolloth Pan, that at Klip Fontein's Berg in Clanwilliam, and the Zwartkops Pan. That the salt obtained in the Colony is generally free of any marked impurity is shown by the analyses of Dr. C. Juritz.[1]

Tin.—Tinstone or cassiterite has been found at several points in the Western Province both in veins and as alluvial deposits. At Annex Langverwacht, near Kuil's River,[2] the cassiterite occurs in veins of quartz and greisen in the granite of the Bottelary-Stellenbosch mass, close to its junction with the Malmesbury slates, and also disseminated through the adjoining granite. It is associated with wolfram and tourmaline, and by the denudation of the ridges a considerable deposit of tin-bearing gravel has been formed on the sloping ground.

[1] "On the Composition of the Salt from some Colonial Salt-pans," *Agric. Journ. C. Colony*, Nov., 1908, p. 648.

[2] H. Griffiths, *Journ. Chem. Min. and Metall. Soc. S. A.*, viii., 1907, p. 167.

At the north-west extremity of the Tygerberg veins of quartz carrying cassiterite occur, apparently in the Malmesbury beds. Several other localities are known at which small amounts of tin have been proved.

The origin of the cassiterite is evidently closely connected with the granite intrusions of the Western Province, and the junctions of the igneous rock with the slates are worthy of more attention than has yet been paid them, while in addition the possibility of important deposits of alluvial tin in the low ground in this area should be borne in mind.

The granites in the Western Province contain a good deal of tourmaline in places, but the presence of that mineral, however, must not be regarded as an important indicator of the existence of cassiterite. Of the other minerals which usually accompany tin ore in various parts of the world, wolfram has been found at Kuil's River and molybdenite in the Helderberg granite along with mispickel, but neither topaz, monazite, nor beryl have yet been recorded.

Water.—The finding of underground water which will either rise to the surface through a bore-hole, or which is within a practicable distance for pumping, is a very important question in the inland and north-western districts. In the folded belt there are permanent streams in the mountains and springs are fairly numerous, but in the interior the majority of farmers are dependent on wells or bore-holes. There are no rocks in the interior of the Colony of such loose texture that they form a "water-bearing" layer. All rocks are traversed by joints, surfaces separating the rocks into large or small blocks, and along some of these are developed cracks which permit water to flow along them. Some of the rain that falls on the ground soaks into it and flows slowly along joints, perhaps escaping as a spring where the surface cuts a joint at a low level. The success of a well or bore-hole depends upon its intersecting these joints below the level of the ground-water of the neighbourhood. The surface of the ground-water varies in position according to circumstances; it rises after rain, and sinks during drought in consequence of leakage from springs, evaporation from the ground, and the daily need of plants; it is brought locally nearer the surface by comparatively impervious bodies of rock, such as dykes of dolerite or large veins of quartz, and this fact is made use of by boring on the supply or up-hill side of such obstructions. There is no ground for suspecting the existence of a large body of water available by deep boring (*i.e.*, over 500 feet or so) in the interior of the Colony, but there is no doubt that the prevention of waste of rain-water, by obstructing sluits and the encouragement of plant growth which will hinder the flow of water over the surface during rain, will increase the supply of ground-water to the benefit of both springs and wells. This process is of the greatest importance in the region occupied by the Karroo formation, where the general shape of the country is well adapted for its success.

An interesting and extremely valuable collection of facts about the composition of spring and well waters has recently been published by Dr. C. F. Juritz.[1] He found amongst other things that the purer waters came from the Table Mountain and Stormberg series and that those from the Uitenhage, Dwyka and Bokkeveld formations were the most saline.

It is impossible to discuss thoroughly the influence of the different formations in various parts of the Colony upon the water supply, but the following brief notes may be of value.

In the granite regions of the North-West and Bechuanaland water is generally got in valleys at the base of the rotten granite, a variable thickness of which overlies the solid rock. The wells in granite, gneiss, or mica-schist are usually of considerable depths. In Northern and Western Cape Colony the Dwyka formation covers many thousands of square miles, and in the majority of instances the water in wells is brackish and often undrinkable. The saline constituents are, however, irregularly distributed through the rock, and it is by no means rare to find two wells side by side, one giving salt water and the other fresh. This peculiarity prevents generalisation, but in a large number of cases the salt is found to have gravitated towards pans and vleis, and better water, usually inferior in quantity however, is obtained on the slopes of the depressions.

Another peculiarity is that where the older formation has been just recently stripped of its covering of Dwyka "tillite" it usually fails to give a strong supply; further away where the "glaciated surface" has been denuded and weathered the conditions become more favourable.

[1] *Agricultural Journal of the Cape of Good Hope*, vol. xxxii., 1908.

In well sinking advantage is commonly taken of what are known as "aars," experience showing that water is usually got at shallower depths there than elsewhere. "Aar" is the name given to any feature on the surface which is very long compared to its breadth; thus it may be applied to the outcrop of a dyke, to a low ridge of limestone, to a slight depression probably marked by a different soil from the surrounding veld, or to a line of country characterised by denser vegetation or by a particular kind of bush. In the Karroo beds the dolerite dykes are of great utility, especially where the formation contains thick close-grained sandstones; the value of the kimberlite dykes as a source of water supply has already been referred to.

It has always been a rule to avoid boring in dolerite, nevertheless in the Northern Karroo many of the horizontal or slightly inclined dolerite sheets are decomposed to a friable sandy material and produce no marked feature. Wells in such dolerite commonly give good supplies, and the water is almost invariably of better quality than that obtained from the adjoining Karroo beds. Owing to the nature of the partly decomposed igneous rock it is more satisfactory to put down a well than to attempt a bore-hole.

In the great dry sandy region of the Kalahari the scanty ground-water is so held by the deep sand that it is not available for collection in wells, and supplies can only be expected in places where the sand is thin, as in the neighbourhood of the German border, and in the tufa-choked beds of the Molopo and Kuruman Rivers.

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